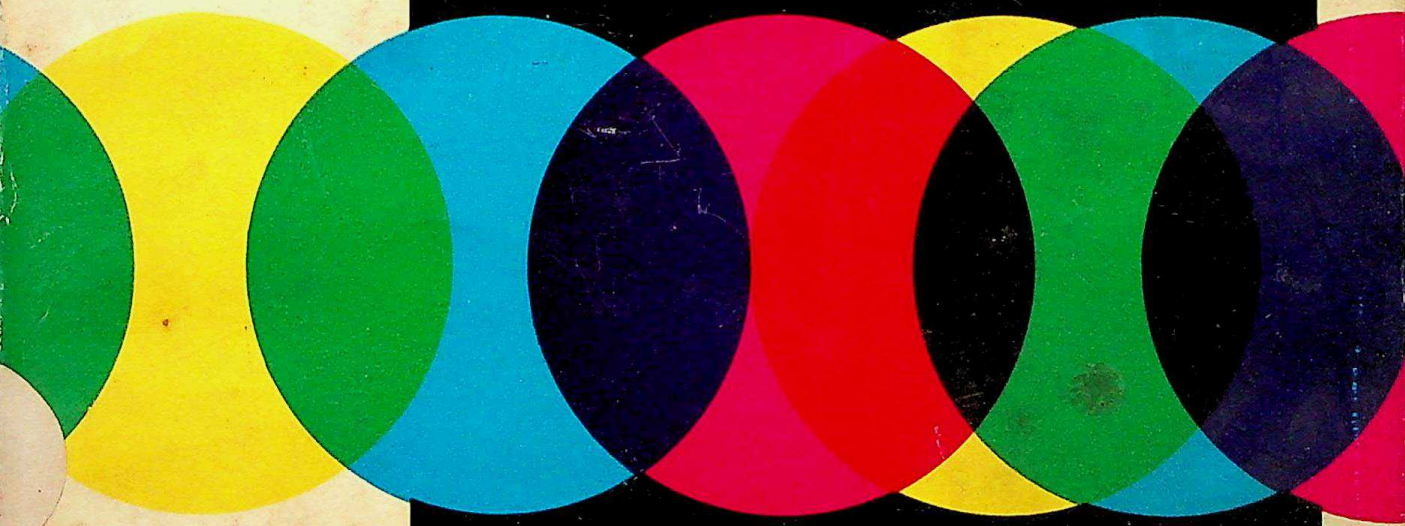
ENCYCLOPEDIA OF COLOUR PHOTOGRAPHY



A FOUNTAIN PHOTOBOOK

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

STATE MUSEUM, LUCKNOW
LIBRARY
Acc. No. 2722
Book No. 778'6
D E

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

7786

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

ENCYCLOPEDIA OF COLOUR PHOTOGRAPHY

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

ENCYCLOPEDIA OF COLOUR PHOTOGRAPHY

FOUNTAIN PRESS LONDON

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

This volume has been produced under the direction of:

M. Déribéré
Secretary General of the Centre d'Information de la Couleur

in collaboration with:

J. M. Baufle
Photographic Laboratory of the Muséum National d'Histoire Naturelle

V. Chappert
S.O.M.

Christian Matras
Cinematographer

A. Ivanoff
Instructor at the École supérieure de Physique et Chimie

Y. le Grand
Instructor at the Muséum National d'Histoire Naturelle

P. Manigault
Chief Photomicrographer at the Institut Pasteur

J. Porchez
Chief Photographer at the Bibliothèque Nationale

J. Stevens
Stereo photography consultant

G. Tendron
of the photographic section of the Muséum National d'Histoire Naturelle

J. Weck
Kodak Colour Research Laboratories

We would also like to express our thanks to Messrs Agfa, Ferrania, Kodak, Mazda, Telcolor, and the 'Science et Nature' for their helpful advice and assistance.

778.6
D E

© Copyright 1962 Fountain Press

Printed in Great Britain by Balding + Mansell Ltd
Park Works, Wisbech, Cambs.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

PREFACE

From the very earliest days of photography, inventors such as Daguerre, hoped to produce a method of recording the full colours of the subject. It was, in fact, not until the beginning of the present century that this aim was finally achieved. Since then some fifty years have passed during which time research and progress have expanded the scope of colour photography so that it now covers as wide a field as black-and-white photography.

Today everyone can take photographs in colour. It is just as easy to load a camera with a colour film as a black-and-white film, and the results can be equally, if not more, satisfactory as long as a few simple rules are observed.

But while the beginner might be easily satisfied, the critical worker will soon discover that it is still far from easy to obtain a true image of a subject, however simple that subject may be. Thus, once started in the search for perfect colour reproduction, the problems of colour photography, for both amateur and professional, seem to grow.

Indeed we find ourselves asking, 'What is colour ?' and can only answer that it is a personal sensation.

How does one interpret this sensation so that there is agreement between the photographer and those who view his photographs ? Much valuable advice is, of course, given by the makers of colour films, and from this we can at least avoid basic mistakes. But this alone does not make us masters of the art.

In fact, apart from the tricks of the trade and the maker's directions, it is through critical observation that we are most likely to make progress, and this often starts with the need to re-train our eye to see colour for what it is, rather than what we think it is.

After so long a tradition of black-and-white photography there has inevitably been some wariness in using colour. And, indeed, having accustomed ourselves to the extreme conventions of a scale of grey tones, many of us are inclined to judge colour photography on this basis.

Though we are all aware of colour, it is something we tend to take for granted. It is only through the eyes of painters, decorators and stage designers that we become pleasurably aware of colour. And if colour photography is to be something more than just a recording medium, we must learn how to achieve a balance between taste and truth in our photographs.

In preparing this encyclopedia we have tried to keep in mind the needs of both the amateur, who is perhaps only at the curious stage, and the professional, already well-grounded in his subject, yet who must always keep ahead of the demands of his everyday practice. On the one hand there is the theory and practice of the various colour

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

processes, the technique of exposure, methods of processing and printing colour films: on the other hand we have tried to cover the aesthetic and psychological approach to colour itself, of the interpretation and presentation of the subject.

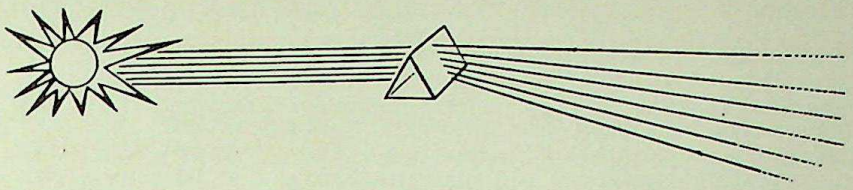
This first French edition appears on the fiftieth anniversary of the first Autochrome plate produced by the Lumière brothers. As this book will bear witness, the path of colour photography has been most varied and diverse since then.

L.C.

In preparing the English edition of the Encyclopedia of Colour Photography we have taken the opportunity of adding notes on any new materials and processes which have been made available since the original French edition appeared.

E.S.B.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



A

ADDITIVE (Processes)

These processes were the first practical solution to a direct colour process.

Based upon the synthesis of white light by the addition of three coloured lights (see *Colour*), the resulting images can only be seen by transmitted light, that is, as transparencies (see page 33).

AUTOCHROME PLATES

It was in 1904 that Louis Lumière described this process in *Comptes Rendus de l'Academie des Sciences* of the 30th May, and it was used to take photographs in 1907.

A glass plate is first coated with an extremely thin layer of minute transparent filters forming a mosaic of orange-red, green and blue-violet dots; this mosaic is made up of dyed starch grains, with a diameter of 15 to 20 microns stuck to the glass with an adhesive layer, and distributed in such a way that a single layer is produced with no overlapping. The spaces between the elements are filled by powdered carbon black and the mosaic is then covered with a protective varnish, after which the screen is highly compressed. By transmitted light the mosaic behaves as a collection of filters transmitting beams of coloured light making up white light, provided that the spectral absorption and distribution of the coloured grains is exactly right. A correctly proportioned mixture appears as a grey powder. The mosaic is then coated with a very thin layer of fast panchromatic emulsion.

Lumière Filmcolor is the present day equivalent of autochrome, with increased speed and greater usefulness.

Usage As the grains of the mosaic behave as filters, the film must be exposed through the base.

To explain the process of colour reproduction a subject comprising colours complementary to those of the filters is chosen, i.e. cyan, magenta and yellow.

During exposure:

yellow is transmitted by the green and orange-red filters; the cyan is transmitted by the blue and green filters; the magenta is transmitted by the orange-red and blue-violet filters.

A pure white would be transmitted by each filter in equal proportions.

The transmitted light affects the emulsion under each grain and after development a single negative silver image is formed which, if the unreduced silver halide were removed, would give an impression of the subject in its complementary colours; that is the yellow appears blue-violet — the colour of the filter which transmits no yellow — the cyan as orange-red and the magenta, green. Instead of fixing, it is usual to convert the negative image to a positive one by a reversal process, which gives:

yellow from the light transmitted by the green and orange-red filters (additive synthesis of yellow); cyan by the light transmitted through the blue-violet and green filters (additive synthesis of cyan); the magenta by the light transmitted through the orange-red and blue-violet (additive synthesis of magenta).

Development First development is carried out in total darkness and is followed by treatment in a bleaching solution designed to completely remove the reduced silver leaving sensitive silver salt under the filter grains which have transmitted no light.

Take yellow for example; it results from the light transmitted by the green and orange-red filters. Second exposure and development of the residual silver halide not previously exposed, behind the blue filter grain, prevents transmission of blue light.

Washing and drying complete processing.

Developing and reversal baths

Concentrated developer:

Distilled water	1,000 cc.
Metoquinone	15 gm.
Sodium sulphite anhyd.	100 gm.
Potassium bromide	10 gm.
Ammonia (·923)	38 cc.

Dissolve the metoquinone in warm water (95° to 105°F) then add the sulphite and bromide and finally the ammonia when the solution is cool.

For use add one part of the concentrated solution in four parts water.

Working temperature 65°F (18°C.)

Develop for ten times as long as the time taken

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

for the image to appear (Watkins' Factor 10).

After rinsing treat in the following solution:

Bleach

Water	1,000 cc.
Potassium permanganate	2 gm.
Sulphuric acid S.G. 1·84	10 cc.
(or Sodium or Potassium bisulphate 25 gm).	

Treatment time 60 to 90 sec. at 65°F. (18°C). or:

Water	1,000 cc.
Potassium dichromate	8 gm.
Sulphuric acid S.G. 1·84	12 cc.

Wash for 5 min. at 65°F (18°C) after bleaching.

Redevelop in the above developer under a 50-watt lamp for 3 to 4 min.

Finally wash for 5 min. in running water and dry.

When the photograph is completely dry it is coated with a protective lacquer.

Filmcolor is made in two types:

Filmcolor A for use in daylight or with electronic flash and Filmcolor B for use with tungsten filament lamps operating at 3,200°K. The speed of Type A is 10 ASA; Filmcolor B gives well-exposed photographs using two 500-watt lamps, an exposure time of 2 to 3 sec. at $f/4·5$, with the lamps 3 ft. from the subject.

DUFAYCOLOR

In the process perfected by Louis Dufay in 1908 the mosaic is made up of a geometric réseau having the appearance of a grid of transparent colours made up of red lines and alternate blue and green squares, twenty tri-colour elements being present in each square millimetre.

The production of the réseau on the base is very ingenious: the base is first coated with a thin, blue-violet collodion layer which is then treated as follows:

1. A series of lines is printed in greasy ink.
2. Removal of blue colour not protected by the ink.
3. The bleached areas are coloured green.
4. Removal of the first greasy ink grid.
5. Printing of a second series of greasy ink lines at right angles to the first.
6. Removal of the colour in the unprotected parts and dyeing orange-red.
7. The protective greasy ink lines are removed and the mosaic is coated with a protective varnish followed by a panchromatic emulsion.

The reversal processing sequence differs little from that used for Filmcolor.

These are the recommended solutions:

Developer:

Water (100°F)	750 cc.
Metol	6·5 gm.
Sodium sulphite anhyd.	50 gm.
Hydroquinone	2 gm.
Sodium carbonate anhyd.	37 gm.
Potassium bromide	2·8 gm.
Potassium thiocyanate	9 gm.
Water to	1 litre

Use without dilution. Develop for 3 min. at 65°F (18°C).

Stop bath (½ min.)

Acetic acid glacial	10 cc.
Water to	1 litre

Wash 2 min.

Hardener (2 min.)

Chrome alum	25 gm.
Water to	1 litre

Wash ½ min.

Bleach (2 to 5 min.)

Solution A

Cold water	750 cc.
Potassium permanganate	0·2 gm.
Ammonium persulphate	0·5 gm.
Water to	1 litre

Solution B

Sulphuric acid conc.	10 cc.
Cold water to	1 litre

For use, mix equal parts A and B.

After this, work can be carried out in ordinary artificial light.

Wash 3 min.

Clearing (½ min.)

Potassium metabisulphite	25 gm.
Water to	1 litre

Wash 1 min.

Again harden for 5 min.

Wash 2 min.

Re-expose for 30 sec. at 3 ft. from a 100 watt lamp.

Re-develop in the same developer for 4 to 5 min. at 65°F.

Wash 10 min.

Dry.

Dufaycolor was made in three types:

D1, roll film, 35 mm. and substandard cine film.

D2, sheet film, in the usual professional sizes.

D4, process film for use in photomicrography, reproduction, etc.

With each type of film a series of compensating filters was available for use with light sources other than those specified.

JOHNSON PROCESS

This is an adaptation of the old Finlay process in which a separate colour screen is used.

The screen is made up of a series of blue-violet, green and orange-red squares, regularly distributed on a glass plate. This is placed in a dark slide in close contact with a panchromatic plate which is then normally developed.

From this negative any number of transparent positives can be printed which, when registered with a screen similar to the taking screen, reproduce the subject in natural colour.

It should be noted that, unlike the reversal method, the separation of the negative and printing stages enables useful corrections to density and contrast to be made.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

ADOX (Reversal colour film)

Adox C18 colour film yields colour transparencies after exposure and reversal processing. It is balanced for use with daylight, blue-coated flashbulbs and electronic flash without a filter, and is available as 35 mm. film.

Adox C18 Color Film, daylight type, 50 ASA

Processing The film must be returned to the approved agents in the bag supplied, and the price of the film includes the cost of processing but not mounting in card mounts.

ADOX COLOR CN17 (Negative colour film)

After exposure and processing Adox CN17 colour film yields negatives from which colour prints or transparencies can be made on any suitable colour print paper or film. The emulsion does not incorporate a mask and the colours are therefore seen as complementary colours. The film is suitable for exposure with daylight, electronic flash, blue-coated flashbulbs, clear flashbulbs, and lamps of 3,400°K and 3,200°K without a filter over the camera lens, unless it is desired to produce negative of uniform colour balance.

Adox CN17, 35 mm., roll- and sheet-film, 40 ASA with daylight.

Processing Two types of processing kits are available: the 'once only' colour developer, Adox Colorfin N, which is supplied in concentrated liquid form in 50 cc. bottles, and the Adox Color Processing kit, which is available as four separately packed ready-to-mix units.

The Colorfin N developer can be diluted according to the requirements of the developing tank, the time of developing being adjusted as follows:

Adox Colorfin N Colour Developer — Temperature 68°F.

Total volume	*Development time*
300 cc.	11–14 min.
400 cc.	13–16 min.
500 cc.	15–18 min.
600 cc.	17–20 min.
700 cc.	19–22 min.

The range of development times gives some control over the negative gradation, the shorter time giving softer and the longer time giving harder negatives.

Fixing bath 5–7 min. at 62°–68°F.

Sodium thiosulphate (cryst.)	200 gm.
Potassium metabisulphate	30 gm.
Water to make	1 litre

Intermediate wash 5–7 min. 57°–62°F.

This and the remaining operations can be done in normal lighting.

Silver solvent 5–7 min. 62°–68°F.

Sodium thiosulphate (cryst.)	40 gm.
Potassium ferricyanide (cryst.)	20 gm.
Potassium metabisulphate	6 gm.
Water to make	1 litre

Wash 20–30 min. 57°–62°F.

Rinse with wetting agent 1 min. 57°–62°F.

AGFACOLOR (Negative-positive process)

Historical Agfacolor negative-positive was the first process using three layer materials for the production of colour prints on paper (1940). The process was used first for motion picture film and the production of paper prints followed. Negative processing can be carried out by the user.

Negative film processing Agfacolor negative has the same structure as the reversal material and is processed to a complementary coloured negative in special Agfa solutions. For optimum results it is absolutely essential to follow the instructions included with each kit.

Agfacolor negative film is available as follows:

CN17, Daylight or artificial light, 32 ASA

CN14, Daylight or artificial light, 20 ASA (35 mm. film only)

Printing positive copies (see Printing)

Agfacolor negative film type ZN — This film is intended for the production of an intermediate negative in the preparation of prints from transparencies.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

PROCESSING OF AGFACOLOR NEGATIVE

	OPERATION	REMARKS	TEMPERATURE	TIME IN MIN.
1	Colour development	Agfacolor negative developer	65°F	6–8½
2	Wash	In running water	55°–68°F	15
3	Bleach	Agfa negative bleach bath	60°–65°F	5
4	Wash	In white light	55°–68°F	5
5	Fix	Agfacolor negative fix	60°–68°F	5
6	Wash	Thorough	55°–68°F	20
7	Dry		not exceeding 90°F	

Note: A correctly processed Agfacolor negative should have a gamma of 0·7: this will then suit Agfacolor Normal Paper CN III.

AGFACOLOR (Reversal process)

Historical The Agfacolor process, first introduced in 1936, should not be confused with processes bearing the same name, which in one case used a three-colour mosaic similar to Autochrome process whilst the other was a lenticular process based on the Berthon process (see Colour Reproduction Processes).

The subtractive Agfacolor reversal process uses incorporated couplers. It has the same layer arrangement as Kodachrome (q.v.) but differs by having in each layer a coupler which during development produces the appropriate colour. The bottom layer, sensitive to red, contains the cyan dye-producing coupler; the middle layer sensitive to green, gives the magenta image; the top layer, sensitive to blue, gives the yellow. The couplers being of a non-diffusing type remain in their proper layers and do not wander into adjacent layers.

Processing Processing of Agfacolor films is undertaken by the manufacturer and independent laboratories; the sequence is similar to other reversal processes.

Three types of emulsion are available:
Agfacolor CT18, Daylight Type, 50 ASA
Agfacolor CK, Tungsten (3,200°K) 32 ASA
Agfacolor CK20, Tungsten (2,900°K) 80 ASA

AIR PHOTOGRAPHY

Photography from aircraft is extensively used for topographical surveys, map-making, archaeology and, in war-time forms a major source of intelligence. Highly specialized cameras have been designed for this kind of work which are electrically operated and take pictures of up to 20 × 20 in. in size. For the amateur, air photography is restricted to chance opportunities through the windows of regular service aircraft or to activities from a flying club. The recent introduction of helicopter excursions also presents favourable opportunities for the amateur. The following advice is intended primarily for the amateur.

Amateur Air Photography The requirements for colour films do not differ very much from those of black-and-white films. The chief problem is that of overcoming the effects of haze and ultraviolet radiation. This can be remedied at moderate altitudes (up to 10,000 ft.) by the use of a Wratten 1A filter when using daylight type colour films. An alternative is to use artificial light type film with a Wratten 85, 85A or 85C filter depending on the colour balance of the film.

When operating with a miniature camera, the best pictorial effects both in colour rendering and definition are from shots made at fairly low altitudes 300–3,000 ft. Large topographical formations such as the Swiss Alps can be photographed satisfactorily at heights of 20,000 ft. and more.

The camera lens can be set to infinity and the largest aperture chosen so as to allow the shortest possible exposure time. The exposure time should not usually exceed 1/50 sec. and should preferably be shorter to allow for aircraft vibration and movement.

The perspex or glass windows of the aircraft will not normally affect the image (so long as they are reasonably clean) and no exposure allowance for them is necessary. At low altitudes, the exposure can be based on normal outdoor photography under similar lighting conditions. At high altitudes from ½ to 1 stop less can be given.

It should be noted that over certain areas and countries, permission to take photographs is required.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Professional photographs In the professional field aerial photography is becoming more and more widely used: cartography, archaeology, agriculture and forestry, geology, prospecting, oceanography (depth of water, location of shoals of fish), physical geography (study of soil erosion) benefit greatly. The use of colour gives results which are more exact, more informative and of easier interpretation. Special emulsions which can be processed immediately on landing have now been perfected. They are balanced to overcome the bluishness due to altitude (or distance of subject) up to 20,000 ft., and for the apochromatic lenses used in aerial cameras. Special emulsions have also been used for the detection of camouflage by recording the shorter wavelengths (violet, blue and green) as green and the longer wavelengths (red and particularly infra-red) as red.

Photogrammetry Photogrammetry is the interpretation of contours on flat photographs which have been taken vertically. In practice this is achieved by wide-base stereoscopy (which is simplified by the movement of the aircraft) facilitating the analysis of relief and topographical features. In photogrammetry highly specialized cameras and films are used. The use of colour can undoubtedly be of great use but so far has hardly progressed beyond the experimental stage. Photogrammetric exposures are made automatically and the equipment obviously requires adjustment when black-and-white emulsions are substituted by special colour film.

ANSCOCHROME & SUPER ANSCOCHROME (Reversal process)

Anscochrome reversal films are of conventional subtractive type using incorporated couplers.

Anscochrome Daylight 32 ASA
Anscochrome Tungsten (2,300°K) (16 mm. and sheet film only) 32 ASA (16 mm.) 25 ASA (sheet)
Super Anscochrome Daylight 100 ASA
Super Anscochrome Tungsten (3,200°K) 100 ASA

PROCESSING OF ANSCOCHROME USING SPECIAL ANSCOCHROME SOLUTIONS

	OPERATION	REMARKS	TEMPERATURE	TIME IN MIN.
1	First development		68°F	16
2	Stop bath	Agitate thoroughly	65°–71°F	2
3	Hardener	Agitate continuously for 1 min.	65°–71°F	4
4	Wash	Running water	65°–71°F	5
5	Re-exposure	Expose each side of the film for 1½ min. at a distance of 3 ft. from a No. 2 photoflood		
6	Colour development	Anscochrome colour developer. Agitate continuously for first ½ min.	68°F	14
7	Stop bath	Agitate	65°–71°F	2
8	Hardener	Agitate continuously for first min. and then at 1 min. intervals	65°–71°F	4
9	Wash	Running water	65°–71°F	5
10	Bleach	Continue for rather longer than the time taken for the back of the film to appear bluish	65°–71°F	5
11	Wash	Running water	65°–71°F	3
12	Fix	Agitate	65°–71°F	4
13	Wash	Running water		10
14	Dry	After wiping		

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Partial development As temperature and humidity can have an appreciable effect on the colour balance of the film if an appreciable time elapses between exposure and development, processing should be carried out soon after exposure. In the Anscochrome process it is possible to carry out the stages of first development and stop bath followed by a 10 min. wash and drying; the reversal exposure and remaining stages being left until later. This partial treatment, which is of particular use in hot climates, should be carried out under the same conditions specified in the table above. The negative image obtained in this way can be inspected in the light without special precautions and can satisfy the examination demanded when crossing certain frontiers.

Forced processing The effective speed of Anscochrome and Super Anscochrome can be modified by changing the first and colour development times as follows:

ANSCOCHROME		
	Developing Time	
ASA	*First*	*Colour*
64	21	16
100	25	16
125	30	20
SUPER ANSCOCHROME		
	Developing Time	
ASA	*First*	*Colour*
150	19	16
200	23	16

ARTIFICIAL LIGHT

A very large number of subjects can only be photographed by artificial light which, unlike daylight, can always be made available. Artificial light is extremely flexible in its application, and is used particularly by the imaginative photographer who can create an atmosphere or an effect with reliable and consistent results.

Correct colour rendering can of course only be obtained when the colour temperature of the light corresponds to the colour temperature for which the film is balanced. Artificial light films may be balanced for 3,400°K, 3,200°K and 2,900°K. It is best to avoid using correction filters and to select lamps which are of the type suited to the preferred film.

INCANDESCENT LAMPS

Incandescent lamps are simple, inexpensive and readily plugged into the mains. They can be used with simple, lightweight reflectors. Any number of lamps can be used near the subject or far from it, giving considerable flexibility. Two types of lamp are suitable for colour photography: photoflood lamps with a colour temperature of 3,400°K and with a life of 2 or 6 hours; or studio lamps with a colour temperature of 3,200°K whose life is from 50 to 100 hours depending on wattage. These life periods are those over which reasonably constant colour temperature can be expected; beyond this period they can only be used for black-and-white photography because of their loss of brightness.

Photoflood lamps These lamps are particularly suitable for amateur use and also by professionals outside the studio; their life, although short, enables a large number of photographs to be taken, particularly if the arrangement of the lamps is carried out while running the lamps at a lower voltage than that used for the actual photographs. This can be achieved by means of a series-parallel switching arrangement where an even number of lamps is in use or with a fixed or variable line resistance which is suitable for any number of lamps.

Photoflood lamps should be used in reflectors; many different types are available, some are large, giving a well spread beam, whilst others give a more concentrated beam. Large reflectors are the most suitable for colour photography where lighting contrasts should be kept low and use made of colour contrasts. For the same reason it is inadvisable to use only one light source. Kodachrome Type A film is the only film currently available balanced for Photoflood lamps of 3,300–3,400°K.

The majority of colour films for tungsten lamps are balanced for 3,200°K, examples being Ektachrome Type B, Agfacolor K, Anscochrome T (sheet film). In this case a correction filter such as the Wratten 81A must be used (see Filters).

PHOTOFLOOD LAMPS
Colour Temperature 3,400°K

TYPE	WATTS	CAP	NOMINAL EFFICIENCY Lm/W	AVERAGE LIFE (hours)	DIMENSIONS	
					LENGTH	DIAMETER
1	275	B.C. or E.S.	29	2	110 mm.	60 mm.
2	500	E.S.*	30	10	160 mm.	80 mm.

*Available with B.C. cap 200–250 volt only.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

In many cases, photofloods can be obtained with an internal reflector. In this case they behave like small concentrated beam spotlamps.

Studio lamps (amateur or professional). These lamps are not over-run to the same extent as photofloods, consequently they have a much longer life. Like photofloods they can be used in any position but are appreciably larger. They are used in reflectors or spotlamps designed for them and lighter weight equipment is now becoming available.

As these lamps require more electricity for a given light output, the motion picture or professional studios using them must have access to adequate current. Their colour temperature of 3,200°K is very stable and has been adopted as the standard for Eastmancolor, Gevacolor, Ferraniacolor, as well as for the Technicolor process.

SERIES B PHOTOGRAPHIC LAMP
Colour Temperature 3,200°K

WATTS	VOLTS	CAP	NOMINAL EFFICIENCY Lm/W	LIFE	DIMENSIONS	
					LENGTH	DIAMETER
500	110, 210, 230, 240, 250	E.S.	21	100	175 mm.	100 mm.

COLOUR CONTROLLED STUDIO LAMPS*
Colour Temperature 3,200°K

REF. NO.	WATTS	VOLTS	CAP	FINISH	AVERAGE LIFE (hours)	
					Low V	High V
CP/1	275	240, 250	B.C. or E.S.	Pearl	5 to 8	
CP/2	500	115, 230, 240, 250	B.C. or E.S.	Pearl	25	15
CP/3	1,000	115, 230, 240	E	Pearl	30	20
CP/4	1,500	115, 230, 240, 250	E	Pearl	50	25
CP/12	2,000	115, 230, 240, 250	Bi-post	Clear	50	
CP/13	5,000	115, 230, 240	Bi-post	Clear	75	
CP/14	10,000	115, 230, 240, 250	Bi-post	Clear	100	

*Typical range only.

FLASHBULBS

Incandescent lamps are particularly useful for interior use when the subject is relatively still or is posed. When rapid movement of the subject is likely, and even for exterior work when artificial lighting is to be used, flashbulbs are indicated. The expendable flashbulb consists of a glass envelope similar to that of an ordinary bulb filled with a long fine wire or fine foil of a special aluminium-magnesium alloy. The foil or wire is in an atmosphere of oxygen at a relatively low pressure and the foil surrounds a tungsten filament suspended between two electrodes leading to the outer connections of the lamp; the tungsten filament is made incandescent when a relatively small current passes between these two contacts. The heating of the filament brings about the detonation of a small charge placed on the electrodes and this in turn causes the foil or wire to burn in the oxygen atmosphere.

Any electrical source capable of momentarily

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

providing a current of 0·4 amp. can be used. Lamps with an E27 Edison screw base can be used either directly off the mains or from a battery. They contain a built-in fuse as a protection against excess current. Lamps fitted with a single contact, small bayonet cap, have no fuse and may only be used with batteries.

Both surfaces of the glass envelope are treated with cellulose varnish. The layer on the inside prevents direct contact between the metal foil and the glass whilst the outer layer reduces the tendency of a fractured bulb to scatter.

Colour temperature of flashbulbs Clear flashbulbs of wire or foil aluminium-magnesium alloy have a colour temperature in the region of 3,800°K. They may be used without a filter with Type F reversal colour films or negative colour films as an indoor light source. Blue flashbulbs have a temperature around 6,000°K and are suitable either as fill-in for daylight or as the main light source using daylight type colour film. At one time a yellow-tinted bulb was available for use with Type A reversal films but the current practice is to use a correction filter, such as the Wratten 81C, with a clear bulb. An 81D filter is required when using a colour film balanced for 3,200°K.

ELECTRONIC FLASH

Electronic flash tubes give a very high intensity and short duration flash. These tubes may be U-shaped or in the form of a spiral and are filled with xenon. The discharge of a condenser through this atmosphere results in a white light of around 6,000°K. The high colour temperature may in some cases give rather blue results as daylight colour films are usually balanced for around 5,600°K. A filter such as the Wratten 81 may be all that is necessary.

FLUORESCENT LAMPS

These lamps now have a very wide use in illumination technique. They are of great interest to the photographer primarily because of the ease with which they provide a general high level of illumination. They also enable a wide range of different effects to be obtained by the use of different phosphor tubes to obtain a particular colour effect. These light sources make use of two different phenomena.

1. The production of ultra-violet radiation by electrical discharge through low pressure mercury vapour.

2. The conversion of this ultra-violet emission into visible light by means of fluorescent phosphors. In this way high luminous efficiency is obtained together with a virtually continuous spectrum which is extremely stable, both of which are desirable in colour photography.

Daylight type colour film may be exposed with 'daylight' type fluorescent strip lighting without a filter.

DISCHARGE LAMPS

We will only mention here the discharge lamps which are capable of giving interesting effects in colour photographs, but which must be used with great care as they do not always give completely reliable results.

Sodium vapour lamps The sodium lamp consists of a U-shaped discharge lamp containing two electrodes; this tube is enclosed in a further vacuum glass envelope to minimize heat losses.

This lamp is run on alternating current via a choke in the case of 220 volt supply or a transformer with a 110 volt supply. Bearing in mind the loss due to the ballast, the efficiency of this form of lighting is very high, being in the region of 60 lum. per watt. The light emitted is restricted to a double line at 5,890–5,896Å, that is virtually a monochromatic yellow.

Types SI85 and SI140 must be mounted horizontally to a tolerance of 20° and must be burnt cap up.

On the other hand Types SI45 and SI60 can be mounted in any position but should still be fitted cap up.

Mercury vapour lamps An electrical discharge through mercury vapour may give radiations of very different spectra according to the pressure of the tube. Thus at a pressure of a few hundredths of a millimetre, emission is principally in the ultra-violet and consists of isolated lines whereas at 20 atmospheres the line spectrum still predominates but on a virtually continuous background giving a high emission of almost white visible light.

This light is highly actinic and is suitable for many photographic purposes. The lamp consists of a small quartz tube, which is thick-walled but of small internal diameter; it is fitted with two electrodes and is enclosed in a larger glass envelope. Lamp types MA80 and MA125 (high pressure mercury vapour lamps) are fed via special equipment.

Mazda Mixa MM300 and MM500 can be run straight off 220 volt mains without auxiliary equipment.

WOOD'S 'BLACK' LAMPS

The MAW Wood's lamp is a high pressure mercury vapour lamp of the MA type which has already been described, but in this case the whole tube is surrounded by an envelope of black nickel oxide

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

glass (Wood's glass). This glass only allows near ultra-violet with a wavelength of about 3,600°A to pass. This radiation has been called 'Wood's light' or 'black light'.

Like the other MA lamps, the MAW types must only be used in conjunction with special feeding equipment.

This 'black light' is capable of exciting any fluorescent material on which it falls. These fluorescent effects can be of the greatest interest not only as music-hall spectacles, but also in scientific applications in analysis, forensic work, and so on.

For this type of work it is necessary to use either panchromatic emulsions or daylight colour film. A filter must be used over the lens so that only the visible light is transmitted, the ultra-violet being absorbed (an aesculine filter for example).

This precaution is absolutely necessary for any objects photographed will reflect the Wood's light strongly and although this is not visible it will adversely affect the photograph or even completely mask the fluorescence. In spite of their apparent brilliant contrast, fluorescent phenomena require prolonged exposures — often in the order of several minutes — but the photographs obtained are extremely striking, especially the coloured ones (see Fluorescence).

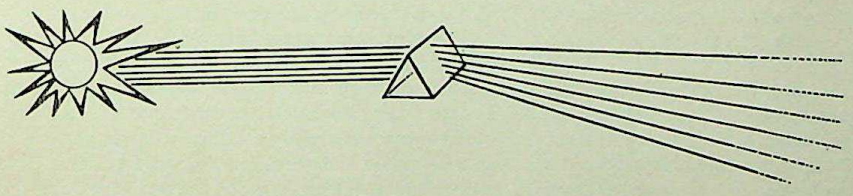
An interesting variation of fluorography is its use in the production of blocks for intaglio printing.

This fluorographic process comprises filling in all the depressions in the original with a fluorescent compound and then photographing this object using a MAW lamp.

The application of the process is extremely simple. The object is dusted with a fine fluorescent powder; alternatively it could be brushed with a paste of the same powder in water or glycerine. A third method is to immerse the object in a fluorescent liquid. The surface of the object is then meticulously cleaned so that the fluorescent material remains only in the fissures, crevices and depressions. The object is then taken into a darkened room, illuminated with a MAW lamp and photographed on either a panchromatic or colour film using an ultra-violet absorbing filter over the lens. The photograph obtained in this way records in the finest detail all the depressions as white.

If it is preferable to record the depressions as black or as complementary colours, the negative itself may be used or a straight print can be made from the transparency.

A variation of this method, suggested by G. Tendron, is to superimpose a fluorographic negative and corresponding positive of different density and to print from the pack. The resulting print has a strange sketchy aspect to which he gave the name 'fluophotographic drawing' but this variation is more suitable for black-and-white than for colour.



B

BLACK-AND-WHITE PRINTS

Objects To obtain prints from colour negatives or transparencies on photographic paper in either the original size or enlarged and in any quantity, or for use as intermediates in the production of photo mechanical prints.

Methods:

Use of a colour negative Colour negatives can be readily printed on to paper or film. Although it is itself coloured it can be printed on to normal bromide paper giving reasonable tonal rendering, whilst the presence of dye particles instead of silver grains may have a tendency to reduce graininess in large magnification enlargements.

From 35 mm. originals on Agfacolor, Ferraniacolor, and Gevacolor, good quality prints up to 10×8 in. can be obtained whilst 120 rollfilm negatives on Kodacolor, Ferraniacolor and Telcolor can be enlarged up to 15 × 12 in.

Enlarging from colour negatives requires no special materials and the methods used for black-and-white work are quite suitable. As it is difficult to judge the printing density of the colour negative it is essential to make stepped test strips and these tests will also indicate the contrast of paper required — usually hard paper. With Kodacolor negatives, which have an integral mask giving an overall orange cast, it is recommended to use Kodak 'Panalure' printing paper.

Printing from transparencies When working from

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

transparencies it is necessary to make an intermediate negative from the transparency; either a same-size or enlarged negative may be prepared. Some colour laboratories will, if requested, provide same-size black-and-white negatives when the transparencies are processed. From these negatives prints of any desired size can be obtained in the usual way.

Photographers wishing to make their own are advised to use an enlarger in the absence of a printer which can give perfect contact between the emulsion of the transparency and that of the negative materials. Even where this condition is satisfied the *thickness* of the colour emulsion and the different strata of the images lead to loss of sharpness; using diffused light there is some inevitable light spread resulting in diffusion of the detail.

This disadvantage is overcome when working by projection in a normal type of enlarger and the original sharpness is retained.

Size of negative The negative size decided upon will be influenced by the size of the prints which are required. If the enlarger will only take negatives the size of the original transparency then it will be necessary to work at a ratio of 1:1 — provided there is adequate extension of the lens — whereas the production of an enlarged negative will require the subsequent use of an enlarger capable of handling the larger negative.

If neither of these conditions can be complied with the solution is to produce an enlarged negative of the same size as the eventual prints, which will be made by contact; such negatives can of course be used for making larger prints with a suitable enlarger.

If the enlarger will accept a negative larger than the original transparency then the largest size negative should be prepared, as the best results are generally obtained from an enlarged negative.

The very best results are always obtained from an enlarged negative which is contact printed. Thus working from 35 mm. transparencies on to a half-plate negative which is contact printed gives better results than enlargements made from a smaller negative.

Choice of emulsion As it is desirable to render all the colours of the original in terms of the corresponding grey density it is necessary to use a well-balanced panchromatic emulsion: these are usually slow- or medium-speed materials which have the further advantage that being fine grained no special developers are required. It is, however, desirable to use a compensating developer in order to obtain a negative with the low contrast and density required for enlarging.

If a small copy negative is to be made it is, of course, essential to use a fine grain panchromatic film: on the other hand if a large negative is to be made for contact printing a faster emulsion can be used as this will give a softer result.

Making the negative As the work must be carried out in total darkness, a suitable means must be adopted for locating the plate on the enlarger baseboard, one method being the use of a movable masking frame.

The thickness of the base must be taken into consideration when working with either plates or film; framing and focusing of the image must be carried out on a piece of very smooth paper (such as fixed-out glossy bromide paper) fixed to a piece of cardboard thick enough to build it up to the same thickness as the plate or film. The plate or film should not be placed directly on the white base of the masking frame but on a sheet of black paper as the anti-halo backing is not itself sufficient to eliminate all reflections.

The transparency should be placed in the negative carrier in such a way that no part of the carrier is unobscured by transparency or mask. No stray light, either direct or reflected from polished objects, must be allowed to reach the sensitive material during the exposure period.

The transparency must be placed in the negative carrier emulsion up so that a negative will be obtained which gives contact prints which are not reversed. When working with plates their flatness is a help; sheet film on the other hand must be placed in a film holder of the type used in dark slides to keep it flat during exposure.

The exposure time depends on so many factors that it can only be determined empirically.

The first tests should be made using a transparency which is normal from the point of view of colour, contrast and density. The speed of the panchromatic emulsions is much greater than that of the papers normally used for enlarging; a small stop — $f/8$ or $f/11$ — should be used and the time controlled with a timer in the lamp circuit.

The test strip method used for bromide paper enlarging is too well known to need further explanation; it is the only method which, used conscienciously, can provide negatives which have the requisite characteristics for black-and-white printing.

Use of filters Panchromatic emulsion behaves towards a colour transparency in roughly the same way as a normal subject as far as filters are concerned and frequently correction filters may be desirable. In fact when taking colour photographs the pictorial effect is usually achieved by means of colour rather than luminosity differences. These colour differences frequently disappear when reproduced in black-and-white. When the amount of light reflected by colour areas is similar they become confused unless there is some brightness

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

modulation. In other cases, however, a subject consisting of a mass of small elements is apt to be confusing.

For example, a bird in a tree will show up well in a colour photograph as a reddish brown object against a green background; this will be completely lost in a straight black-and-white reproduction. If an orange filter is used when making the negative the green foliage will be subdued on the print and the bird will stand out in lighter tones; a green filter will give the opposite effect. In the same way a blue sky can be darkened or lightened by using a yellow or blue filter and a wide variety of effects can be obtained by varying the colour of the correction filter.

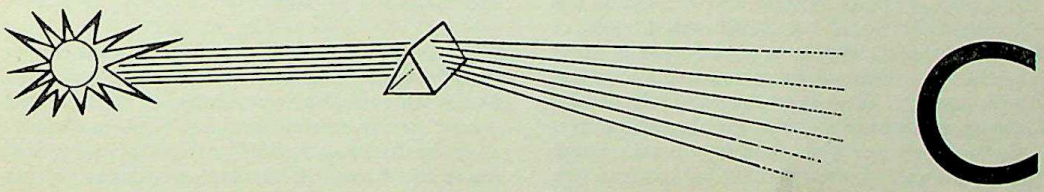
The filters commonly used in monochrome photography can be used for this black-and-white work even including separation filters if the degree of correction required is great enough, and their factors using artificial light must be considered. Filters may be used over the lens, as when taking normal photographs, but the best place is behind the condenser; many modern enlargers with an anticipated use in colour photography have a filter drawer incorporated.

Highlight and Shadow Negatives A colour transparency generally has high contrast and if the extreme shadows and highlights are to be reproduced faithfully a soft gradation negative must be made, but the resulting prints will generally be flat. Printing on to hard paper will not achieve the desired end, only the mid-tones being well reproduced. A technique which has already been used for black-and-white work (derived from the Person process) makes use of two negatives: one is made on a normal emulsion and is slightly underexposed to give the best recording of the highlights, at the expense of the shadows: the other negative is made on a contrasty emulsion to record all the shadow detail.

In fact the brightness range of these two negatives should correspond to that of a normal paper; the mid-tones are, in fact, somewhat distorted but this is of minor importance as it is not the mid-tones which give character to the photograph. The printing method is to print first from the shadow and then from the highlight one.

The requisite accurate registration is carried out by manipulation in orange light using registration marks on the negative such as two widely separated perforations of a 35 mm. original or small crosses made on the original when using other sizes; these appear on both negatives and by marking the paper with a fine pencil when the first is printed, a visible guide is given for the registration of the second.

Here again, test strips enable a judicious balance to be achieved between exposures through the two negatives.



CAMERAS

Photographic colour reproduction is achieved by synthesis and it is necessary when taking the photograph to adopt a system of analysis. Choice of camera will depend on whether the analysis is achieved by making three direct separation negatives or by the use of an additive or subtractive process on a single support.

Direct separations Inanimate objects which can be kept stationary and illuminated with light of constant intensity and colour can be used for direct separation negatives, particularly documents, works of art and still life subjects. Under these conditions any camera, from a process camera to a miniature which can be focused and framed at close distances, can be used provided that it has a well-corrected lens.

If a moving subject is to be photographed, the time elapsing between the three successive exposure is much greater than the permissible tolerance between the three records. There are several different methods of achieving a more rapid change of plates and filters to reduce the total elapsed time.

Repeating backs In this type of instrument the normal camera back is replaced by a special slide which automatically exposes the three separation plates successively; at the same time the corresponding three filters are automatically changed in

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

front of the lens.

The simple types are generally preferable and these, under average conditions, have a time lapse of about five seconds for the exposure of the three negatives. With more complex types in which the exposure is automatically varied for each plate the total time can be shortened to as little as one second.

One shot cameras Mechanical methods involving successive exposures even at their best require the subject to be stationary for an appreciable period; for instantaneous photographs optical means must be adopted for the simultaneous production of the separation negatives. Owing to parallax errors the use of multi-lens systems is ruled out and it is therefore necessary to use prisms or partially reflecting mirrors to divide the light from a lens and produce three similar images.

Although these cameras give excellent results, modern integral tri-pack colour processes have virtually relegated them to the museum.

Direct colour processes Any camera with a well-corrected lens and an accurate shutter is capable of giving consistent results. The type and size will be determined by the work to be done, which falls into two main categories.

1. Work intended for photomechanical reproduction for which either a transparency, a negative-positive print or direct separations may be required.

   Sheet film is used in any large size camera (e.g. 5 × 7 in., or 8 × 10 in.) suitable for studio use with artificial lighting and for certain exterior work. For the latter, however, 4 × 5 in. or even 3½ × 2½ in. apparatus is preferable as many of the latest cameras incorporate all the necessary features. Thanks to their interchangeable lenses mounted in shutters, together with range-finder or ground-glass focusing and the possibility of using colour rollfilm in a roll holder, these cameras are suitable for all types of photography if transparencies for projection are not required.
2. Colour photographs primarily for projection but which can also be printed photographically or by photomechanical means.

The sensitive material — negative or reversal — may be 35 mm. or one of the rollfilm sizes.

35 mm. Cameras Subtractive colour film was first used in this size and for some time film was only available in this size.

Undoubtedly cameras of this size are at the present time most widely used for colour photography. The low price of each picture is one of the main factors contributing to their success. As most colour emulsions are of moderate speed the wide apertures of miniature camera lenses together with their considerable depth of field is beneficial for photography under poor conditions. The wide range of available interchangeable lenses with cameras such as the Leica, make them suitable for a very wide range of work.

The 24 × 36 mm. format is the best size for projection, thanks to the small size of the mounted transparencies and the wide range of available projectors. The dislike of this size by many graphic arts technicians has its origin in the considerable degree of enlargement which is frequently called for; this cannot be disputed in the case of transparencies of inadequate sharpness but does not apply to the purely technical considerations of colour reproduction, in the different stages of a photomechanical process: separating, masking, etc, are the same for a 24 × 36 mm. original as for the more acceptable 6 × 6 cm. one.

Rollfilm cameras The 6 × 6 cm. format has the advantage of not requiring so much enlargement and the fact that the transparency can be viewed without the aid of an optical viewer.

The softer gradation of rollfilm compared with certain 35 mm. processes should also be mentioned; this partially explains the better colour rendering. Personal preferences in the choice of a camera are the same for colour as for black-and-white photography, but undoubtedly the relatively short focal length of the lenses, which may not be interchangeable, is a disadvantage of most of these cameras. Furthermore, a reduced range of high-quality projectors in addition to their higher price compared with the 24 × 36 mm. projectors, limits the popularity of this size.

Lenses Naturally the choice of lens for colour photography is important but it is not necessary, as certain manufacturers imply, to have special correction for colour work. A good anastigmat suitable for black-and-white work is quite adequate for colour. With the introduction of fast colour films the need for a very large aperture lens is no longer so important.

The conventional method of specifying the lens aperture in terms of its *f*/ number does not give the actual photometric aperture as the transmission of a lens depends somewhat on its design, e.g. the number of components, etc. To overcome this a new system known as 'T'-stops has been introduced which is based on the actual photometric transmission of the lens.

The use of long focus lenses with an aperture exceeding *f*/5·6 sometimes leads to vignetting which cannot be corrected as colour transparencies are not generally enlarged. To overcome this difficulty some wide aperture lenses, such as the *f*/1·5 Summitar, have a front element which is much larger than the actual aperture.

The colour change produced by the lens is of

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

the greatest importance and must be carefully ascertained by systematic tests. Simple, small-aperture lenses produce no practical change but some optical glasses such as lanthanum glasses are far from colourless. Some of the modern series of interchangeable lenses are accurately matched for colour. With others, small variations can be corrected by the use of colour-compensating filters such as the Kodak CC series.

A lens hood is usually a desirable accessory in colour photography.

Shutters Here also it is advisable to use only the best makes. No two shutters are identical, and it is only with experience that the relationship between the marked and actual speeds can be established. It is, however, essential that the ratio of the speeds to one another is constant, the determination of the shutter speed being linked with the selection of aperture. The exposure time must be carefully standardized over the range, particularly as between-the-lens shutters tend to under-expose at speeds exceeding 1/250th second whilst focal plane shutters may over-expose at 1/10th of a second or more (see Shutter calibration).

In the case of single-lens reflex cameras, particular attention must be paid to the freedom from vibration caused by raising the mirror.

With the growing use of flash as the main or auxiliary light source, all modern shutters are synchronized for use with flashbulbs or electronic flash.

Cassettes With the increasing use of colour photography, the photographer is faced with the problem of whether to load his camera with black-and-white or with colour film for it is by no means certain which will be required. For those having two cameras the problem is resolved into which type of film will be used with each size of camera. Several manufacturers have perfected cameras in which the lenses and accessories are interchangeable, including an interchangeable back which allows the film to be changed in a matter of seconds, typical examples of which are the Contarex and Contaflex cameras. For some time Leitz have manufactured relatively simple camera bodies which are little more than film holders and to which the lenses and other accessories of a normal camera can be fitted. In one case — the Hasselblad — interchangeable magazines are available.

These methods are of considerable interest for it is also possible to change from a daylight balanced colour film to one designed for exposure to tungsten light.

It is of the greatest importance to make sure that all camera parts and film holders are thoroughly cleaned to avoid spots and other marks which cannot be removed from a colour film by retouching.

Viewfinder A special aspect of colour photography should be noted: this is the importance of accurate framing. It is virtually impossible to make adjustments to the framing when transparencies are taken and it is not desirable to take the required area from a larger format original.

With an 'optical' viewfinder it is essential to compare the field of view of the viewfinder with the image produced on the film so that parallax errors can be avoided, particularly when working at close distances.

The single-lens reflex has the valuable advantage that the image seen in the viewfinder is in all respects similar to that produced on the film but there is a tendency towards vignetting when the lens and film are a considerable distance apart as in photomacrography or telephotography.

The view seen with a twin-lens reflex must to a great extent be estimated and parallax corrections must be marked up on the ground glass.

With all colour photographs attention must be paid to keep the frame horizontal as errors cannot be corrected at a later stage.

A good colour camera The modern eye-level reflex camera with provision for interchangeable lenses is probably the ideal choice for the colour worker since the two most important aspects in colour photography are accuracy in framing and the ability to fill the available picture area. Ease and accuracy in focusing are also desirable as well as such features as interchangeable backs or film cassettes. However, excellent results can be obtained with any well-made camera and even a simple box camera can be made to yield acceptable snapshots.

It is desirable to test the lenses, cassettes and other accessories in conjunction with the film which is usually used.

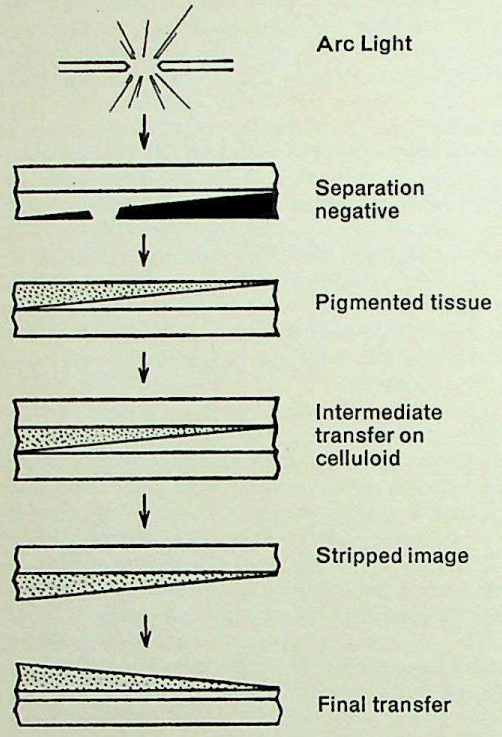
CARBON PROCESS

It was Poitevin who, in 1855, perfected the use of bichromate sensitization in the carbon process. A gelatin layer in which extremely fine carbon particles are dispersed is sensitized by immersion in a solution of bichromate. After drying and exposing to an arc lamp, a film of hardened gelatin is obtained after hot-water washing; this thin film can be used for the production of an image via a suitable transfer system. The difficulty of exposing through an irregular, dense and grainy paper base, made it necessary to use an intermediate polished support, such as celluloid, for the hardened image

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

which is then transferred on to a suitably treated gelatin-coated paper. Furthermore it has been found desirable to incorporate a dye — particularly a yellow dye — into the bichromated layer to restrict the penetration of light.

This restriction assists the formation of a relief image, the dye generally being washed out when the layer is hot-water developed. The procedure for using the carbon process in the production of a three-colour print can be summarized as follows:



Three sheets of pigmented tissue, yellow, magenta and cyan respectively, are sensitized with a bichromate solution and exposed behind suitable separation negatives — the yellow tissue behind the blue separation, the magenta tissue behind the green separation and the cyan tissue behind the red separation. As with the Carbro Process (q.v.) hot-water development is preceded by a transfer operation on to a temporary polished support (celluloid sheets which have been waxed). The well-polished celluloid and the tissue are brought into contact under water, blotted off and dried for about twenty minutes.

After drying the adhesion between the hardened part of the tissue and the waxed celluloid is sufficient to allow the tissue support to be stripped off by immersing the sandwich in water at 120°F, which dissolves the unhardened gelatin. Washing is continued until all traces of unhardened gelatin have been removed. To set the relief image a final rinse in cold water is given and the three celluloids are dried together to avoid any relative changes in size.

The final stage is to transfer the three images successively on to a sheet of gelatin-coated and hardened paper by squeegeeing down and drying. After a certain time the gelatin relief and the gelatin-coated paper adhere well enough to permit the paper bearing one or more images to be stripped completely from the celluloid. With successive exact registration a final three colour print is assembled.

CARBRO PROCESS

The sensitivity of bichromated gelatin as used in the carbon process (q.v.) is so low that enlargements cannot be made, and to overcome this an intermediate — a silver halide photographic print — is used in the carbro process. The method uses a principle discovered by Farmer in 1889 in which a silver image bleached by dichromate can be used to differentially harden a pigmented tissue in proportion to the amount of silver present. In the carbro process, printing of the separation negatives is not carried out directly on to pigmented tissue containing silver halide but on to a group of three separate sheets of bromide paper, giving bromide prints (from which the name of the process is derived); at this stage three pigmented tissues of magenta, cyan and yellow have been suitably sensitized with bichromate. In this case the bichromate plays no part as a photo-sensitive material but solely as an oxidizing agent by using a special solution which is allowed to act upon the sandwich of bromide print and tissue for a period of about ten minutes. This solution, which is a bleaching bath containing potassium ferricyanide with an excess of potassium bromide, converts the silver image to silver bromide, during which operation the ferricyanide is reduced to ferrocyanide; it is this ferrocyanide which reduces the bichromate in the tissue to give chromium salts which harden the gelatin locally.

Silver metal + potassium ferricyanide and bromide → Silver bromide + potassium ferrocyanide

Potassium ferrocyanide + potassium bichromate → Potassium ferricyanide + Chromium salts

Chromic salts + gelatin → Hardened gelatin

In the succeeding operations the tissues are

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

applied to sheets of waxed celluloid as in the carbon process but it is necessary to use a double transfer system in order to have the final image the right way round. It is, in fact, necessary to avoid inversion of an image which has not been exposed directly on to the tissue but indirectly via a bromide print; this intermediate transfer is carried on to a paper coated with soft gelatin to which the relief images are applied before finally transferring on to suitable paper coated with hardened gelatin which constitutes the final support as in the carbon process. The transfer order depends mainly on the transparency of the pigments used; the least transparent being the first which is applied to the final support.

CARBRO (PRACTICAL DETAILS)

Carbro is a fairly complicated process but one which can give excellent results.

The basic photographic operation is the preparation of three separation negatives made directly from the subject or from a colour transparency. (See separation negatives.) The size of these negatives is not of primary importance as printing is best carried out in the enlarger.

Material Matt bromide paper without an anti-stress layer: paper coated with pigmented gelatin in cyan, magenta and yellow: celluloid sheets 0·015–0·020 in. thick: plate glass: a rubber squeegee: an illuminated viewing table or printing box large enough for registering the separate images: a seconds timer.

The working procedure is as follows:

Printing of the bromides Projection printing has the advantage that double transfer can be avoided, all that is necessary is to invert the negative in the negative carrier. The bromide images, being reversed, give a final image which is correct. For final registration to be possible it is absolutely essential that all prints are made with the paper running in the same direction — this is easily recognized from the direction in which the paper curls when left in the air. For the same reason the three sheets of pigmented paper must also be cut in the same direction. When making the bromide prints a ⅜ in. margin around the image should be left.

The exposure time which must be carefully controlled, is based upon the requirement that the lightest highlight detail should just be visible after two minutes development at 65°F. After this, development should be stopped.

Developing solution: The best solution is the well-known amidol one.

Sodium sulphite anhyd.	50 gm.
Potassium bromide	1 gm.
Water to	1 litre

When dissolved add:

Amidol	5 gm.

This bath, which does not keep well, should be mixed just before use.

Fixing After rinsing, the prints should be fixed in a non-hardening acid fixer and thoroughly washed.

They can be used immediately or dried for use later. Just before use immerse in 2 per cent acetic acid.

Preparation of celluloids The celluloid sheets should be appreciably larger than the sheets of tissue which are applied to them. For stripping to be even, the celluloids must be meticulously polished. Dissolve a piece of bees-wax and a piece of resin, each as big as a pea, in 150 cc. of benzene. Moisten a piece of very clean flannel with this solution and apply all over the celluloid using a circular movement. Using a piece of fine cotton remove the excess wax and work up a polish; only a very thin, even layer of wax must remain on the celluloid. The celluloids must be prepared at least an hour before they are required.

Sensitizing pigment paper The pigment paper should be sensitized in the following solution:

(*a*) Stock solution:

Potassium ferricyanide	100 gm.
Potassium bromide	100 gm.
Distilled water to	1 litre

(*b*) Stock solution:

Potassium bichromate	40 gm.
Chromic acid	9 gm.
Chrome alum	20 gm.
Distilled water to	1 litre

Just before use dilute as follows:

1. Solution A	1 part
Distilled water	4 parts
2. Solution B	1 part
Distilled water	4 parts

The first solution can be used for a large number of prints but the second must be discarded after each group of three tissues.

The solutions are used at a temperature of 65°F.

Working procedure:

1. Cut the pigmented tissue into pieces ⅜ in. bigger all round than the bromide paper.
2. Arrange in the following order:
   a dish containing sensitizer part 1
   a dish containing sensitizer part 2
   a dish of water for the bromide prints
   a sheet of plate glass
   a large dish of cold water.
3. After marking the three bromides C, M, Y to indicate their colour, immerse the sheet of yellow pigmented paper into the dish containing sensitizer number 1, taking care to avoid any air bells.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

4. As soon as the pigment paper is placed in the first solution, remove the yellow bromide from the water and place it face upwards on the plate glass; remove the surface moisture with the rubber squeegee.
5. After three minutes' immersion in the first solution the tissue is withdrawn, drained for 5 sec. and placed face down in the second sensitizer for 30 sec., during which period the dish must be constantly rocked.
6. Take the pigment paper out of solution number 2 and immediately lay it on to the bromide paper with a rapid rolling down motion starting at one side; this must be done quickly and smoothly. As the chemical action is immediate, no slipping must occur or a double image will result. Squeegee the two sheets together using the squeegee in all directions.
7. Remove the two papers from the glass, easing the corner up with a penknife, and place between moistened blotting paper under light pressure.
8. Leave the two in contact for 10 min., which is a sufficient time to completely bleach the bromide and ensure the corresponding imagewise hardening of the pigmented gelatin.

   The time of immersion in the second sensitizer affects the contrast of the final image: reduced time increases contrast whereas increased time give a soft result.
9. After 10 to 15 min. slide one of the sheets of celluloid, waxed-side uppermost, in to the dish of cold water. Strip the tissue from the bromide (the latter being returned to a dish of water) and place the tissue face down on to the waxed surface of the celluloid. Remove the celluloid with the celluloid and tissue from the dish with a vertical sweep to drain off as much of the water as possible, remove the excess moisture with the squeegee, and turn the celluloid over to check that there are no air bells between the tissue and celluloid; if so the operation must be repeated. Place between two sheets of blotting paper and leave under light pressure for 20 min.
10. The image can now be 'developed'.

    For this operation a large, deep dish and a considerable amount of hot water are required.

    Fill the dish with water and adjust the temperature to 110°F. (It is beneficial to work in a hot, damp atmosphere; it is in fact essential to remove the gelatin in the hot water without allowing it to become hardened by exposure to air). Slide the celluloid and tissue into the hot water with the tissue uppermost. After 1 to 2 min. the gelatin of the pigment paper starts to dissolve at the edges.

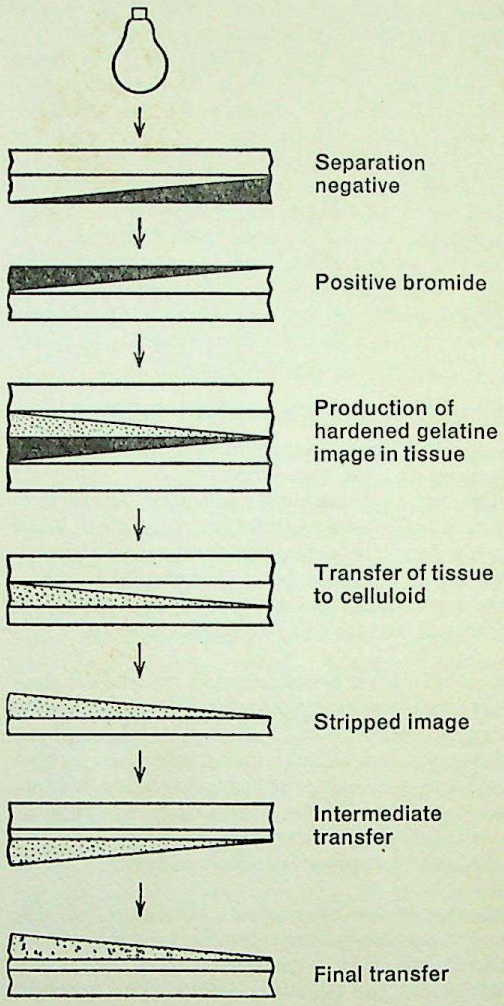
    Lift one corner of the tissue support with the fingernail and, still under the water, gently strip the paper from the celluloid. This leaves a layer of pigmented gelatin adhering to the celluloid, part of which dissolves leaving the insoluble image.

    Gently move about in warm water until the soft gelatin is completely dissolved. To remove all traces of soluble gelatin, rinse the image under the hot tap.

    There is some danger that final stripping may be affected if at this stage the atmosphere is cold and dry.
11. Change the water in the dish, which must be kept constant at 110°F.

    Make sure that the operation is complete by looking through the image and then dip into a dish of cold water for a few seconds before drying in a current of clean air.

    The same sequence of operations is carried out for the magenta and cyan images, each being on its own celluloid support.



CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

12. The images are now transferred on to a piece of gelatin-coated paper. The paper must have a smooth surface; grained papers require a double transfer technique. The transfer paper should be about ½ in. bigger all round than the image.
13. Place the transfer paper face down in a dish of cold water and when the edges show a tendency to curl back, slide the yellow celluloid, image up, under the paper. Position the paper carefully, remove the two from the water, thoroughly squeegee and leave to dry in a current of clean air.
14. When the transfer paper is dry it will fall from the celluloid carrying with it the yellow image.
15. The paper is again placed face down in a dish of cold water. When the edges begin to curl up slide in the celluloid leaving the magenta image so that the two images correspond.

    Drain quickly and place the two on the viewing table or printing box. Slide the paper around until the two images are exactly registered. Work quickly to avoid damaging either image and, when in position, squeegee together.
16. Place a sheet of cellophane, considerably larger than the print, on to the back of the transfer paper and place on it the celluloid carrying the cyan image. The use of this image shows up errors in registration of the yellow and magenta images. The balance can also be checked at the same time.
17. Remove the cyan celluloid and the cellophane and dry the yellow plus magenta image as before.
18. Again the paper falls off, this time taking with it the magenta image.
19. Transfer the blue image in the same way as the red image.
20. When the base dries off the final support the colour image will be complete.
21. To obtain a smooth finish the prints must be resoaked in water and squeegeed on to plate glass, as when glazing a bromide print. If hot glazing is to be carried out a little formalin should be added to the water used for resoaking.

CHILD PHOTOGRAPHY

Successful child photography demands patience and also complete familiarity with equipment and materials. The camera should have a viewfinder which enables rapid movements to be followed and a simple and accurate focusing system.

Shutter speed As children are liable to move suddenly the shutter speed should not be less than 1/50 sec. — the usual setting for colour photography. It is better to work at 1/100 sec. if lighting conditions permit and the new faster emulsions are a help. At these shutter speeds a medium aperture is required giving a certain margin in focusing without which the work would be extremely difficult. This does not apply under exceptional conditions when to use a faster shutter speed a wide aperture must also be used. No attempt should be made to follow the movements of the children by continually changing focus. It is better to decide on the most suitable distance and keep this constant by advancing to or retreating from the subject. Reflex finders are preferable to rangefinders giving equal precision and a much larger image. An aperture of *f*/8 gives sufficient depth of field to keep the entire subject sharp, for although the face is the centre of interest other parts of the body should not be noticeably unsharp. Other matters such as the posing of the subject, the best angle of view and so on, are similar to those encountered in black-and-white photography and need not be discussed here.

Outdoor work The most attractive colour photographs of children are frequently those taken out of doors in fine weather. Beach or country backgrounds in an open setting are the most attractive. They are the simpler to compose as the number of unwanted objects likely to intrude into the field of view is small. The general surrounding colours are also pleasing. The colour rendering of the delicate infant skin textures is of great importance. As in all branches of colour photography, a single bright colour or a coloured object such as a toy does not offend, but it is essential that this coloured patch is not too dominant. Large deep shadows are out of place in child photography. These are unnecessary in colour work where delicate tints are readily separated, as opposed to black-and-white where they are all rendered as even greys. Hence the desirability of finding an angle which will give the necessary low contrast range having only small shadow areas which would otherwise have to be lit.

On the beach the light reflected from the sand is very useful in lightening the shadows but if a white reflecting surface can be included so much the better. The familiar white card reflector held outside the field of view which is very useful in general portraiture, may not be suitable for use with a child who is continually changing his position and attitude.

Direct lighting is not essential; the open shade of a tree or white wall can give pleasing results

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

provided no colour cast is produced. The usual precautions should be taken against including very brilliant areas in the photograph.

Reflections When photographing children the effect of reflections is of very great importance as colour rendering must be accurate. The presence of a green lawn in front of the child or a brick wall in the vicinity should be avoided. In the first case green light is reflected into the face and the second results in an unpleasant reddish cast. These factors are less important when situated behind a subject as they then produce no appreciable effect. If the sky is slightly overcast and the light diffuse the reflections are less obvious.

Filters The composition of daylight varies considerably depending upon the time and the weather; it is often desirable to use correction filters:

To reduce the warmth of evening light

To eliminate excess blue, particularly from the shadows when the sun is shining.

The blue sky with no clouds results in extremely blue shadows but this effect is considerably reduced by the presence of white clouds. In either case the highlights will have a tendency to appear warm due to the contrast with the shadows. If the sky is overcast, the light is diffused and bluish but the effect is not unpleasant as the whole subject is affected. (For information on the use of filters see this heading.)

Contre-jour effects When photographing against the light the foregoing remarks concerning shadows still apply and photographs taken in this way give very pleasing results in which colour casts in the skin are more acceptable than they would be with frontal lighting.

As the photograph is generally to show more than a simple silhouette, the exposure should be for the shadows and exposure meter measurement must be taken very close to the subject so that the brilliant highlights do not affect the reading. Measurements need not be made on the actual subject and can even be made on the photographer's hand oriented in the same plane as the subject.

The highlights will be considerably over-exposed but the overall effect in the photograph will be the same as the effect seen in the viewfinder. The highlights should occupy as little of the picture as possible.

Supplementary lighting If a contre-jour effect is required, supplementary flash lighting is beneficial in lighting up the shaded face to avoid excessive contrast.

To maintain the contre-jour effect the intensity of the flash and that of the sun should be balanced so that the sun is still dominant. The flash should have approximately one-third the brightness. This balance is achieved in the following way:

First calculate for the direct sunlight and reduce the exposure by $\frac{1}{2}$ stop. Find the guide number for the particular flash bulb at the shutter speed being used.

Multiply this number by 1·7 (square root of 3) and divide this number by the aperture. The quotient is the distance between the lamp and the subject.

Artificial light Normal or overrun tungsten lamps of the type used for black-and-white work are not ideal for child photography in colour because of the moderate speed of colour film and the consequent long exposures required. It is better to use flash together with artificial light film; the flash exposure is short enough to stop most movement. The ideal lighting is, perhaps, that of electronic flash units. This gives excellent colour-rendering with daylight type films and the extremely short duration of the flash eliminates any danger from movement.

For the characteristics of artificial light sources see under 'Artificial Light' and for data or flash lamps see 'Exposure'.

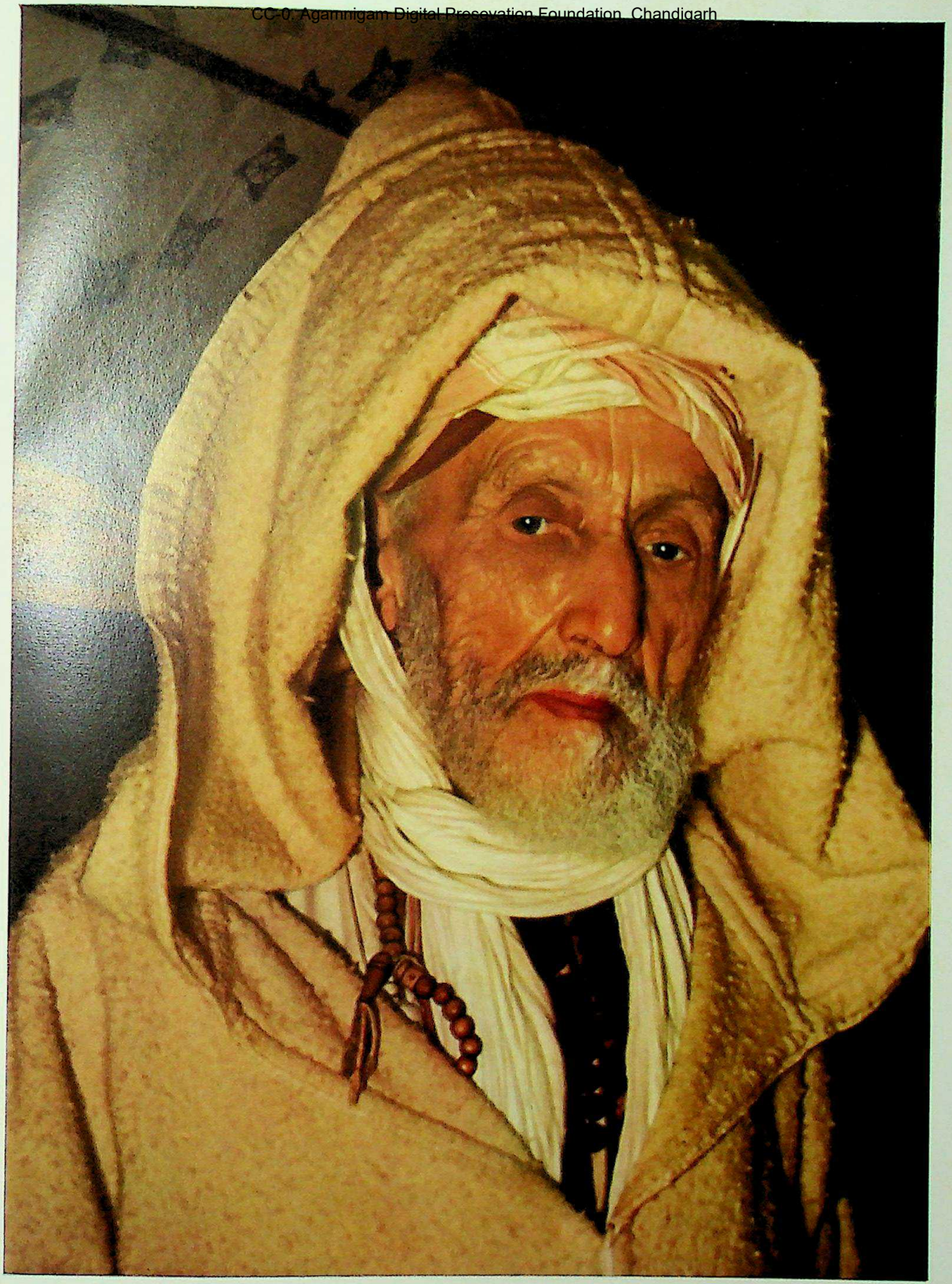
CHIMICOLOR PROCESS

The Chimicolor printing process, like the Supercinecolor process (q.v.) uses a film base which is coated on both sides and on which cyan and magenta images are obtained via a mordant process.

The third image is applied using the Pinatype process (q.v.); the side carrying the magenta image is bichromate sensitized and exposed behind the blue record negative using a registration printer fitted with a high-power, mercury vapour lamp. The exposed parts are strongly hardened and the contraction of the gelatin is sufficient to enable a yellow dye to be preferentially absorbed in the unhardened areas.

In practice it is essential that the yellow acid Pinatype dye is compatible with the magenta basic dye used for the mordanted image.

CC-0. Agamnigam Digital Preservation Foundation, Chandigarh



OLD MOOR — an ethnological study by D.I. Maudry taken with a Contax by flashlight

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

STUDY IN CRYSTAL FORMATION — photomicrograph made with a Contax and Panflex

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CHROMATONE

The Chromatone process, introduced by the Defender Company in 1936, makes use of a toned silver image.

General The name 'colour toning' is applied to processes in which the silver image is used to control the quantity of a coloured pigment produced. In the alternative method (dyeing) the silver image is converted to a mordant which differentially absorbs dye from a solution.

In the toning processes, the silver image is usually converted to silver bromide or ferrocyanide and at the same time an insoluble salt of another metal is deposited *in situ*. The latter can be converted to pigment in a further stage. The most familiar toning method gives an image of Prussian blue (ferric ferrocyanide).

The first stage is to convert the silver image to silver ferrocyanide with potassium ferricyanide. The silver ferrocyanide then reacts with a ferric salt to give Prussian blue. The silver salt which is also produced can be removed with a hypo solution. Research in this field has been directed towards obtaining yellow, magenta and cyan images by such a process.

In this context, a magenta pigment can be obtained by producing the reddish-magenta nickel dimethylglyoxime in the layer.

To do this the silver image is converted to nickel ferrocyanide by the combined action of potassium ferricyanide and a nickel salt. The nickel ferrocyanide is finally converted to nickel dimethylglyoxime by treatment in an alkaline or ammoniacal solution of dimethylglyoxime.

Finally, the yellow image is obtained by converting the silver image to cadmium ferrocyanide, which is itself converted to cadmium sulphide by treatment in a solution of sodium sulphide.

Other pigments such as vanadium ferrocyanide and lead chromate have been proposed for this image.

In the Chromatone process, the three images were obtained by printing from separation negatives on to a stripping material comprising a paper base carrying a removable collodion layer on which the emulsion is coated.

After the three images have been converted to ferric ferrocyanide, nickel dimethylglyoxime and cadmium sulphide, they are superimposed in register on a gelatin-coated paper after removal of their original paper bases.

COLORIMETRY

PHOTOMETRIC POTENTIALITY OF THE EYE

To define the physical characteristics of light in a satisfactory way (see Colour) the visual evaluation of colour by the eye uses a complex three-colour process. (See Section on Colour Vision.)

The way in which the eye reacts to variation in colour stimuli is the essential feature of colorimetry.

COLORIMETRY

Introduction When the eye examines a colour it distinguishes three main properties. The first is the lightness of the colour. Like all other organs the eye can only work by comparison; the intensity of a colour can only be evaluated with reference to another colour. When two similar colours of different density are placed side by side in the visual field, they exhibit what is known as intensity difference, and it is through this intensity difference as well as the colour difference that surrounding objects are seen.

Another property is known as the *dominant*. Generally speaking, any colour is reminiscent of a known spectral colour; in principle any green is related to a well defined spectral green. Thus a given colour is made up of mixtures of a dominant with an important proportion of white light; a saturated colour results from the presence of a large proportion of the dominant with little white. The saturation of a colour becomes higher as its purity increases — as it becomes less washed out.

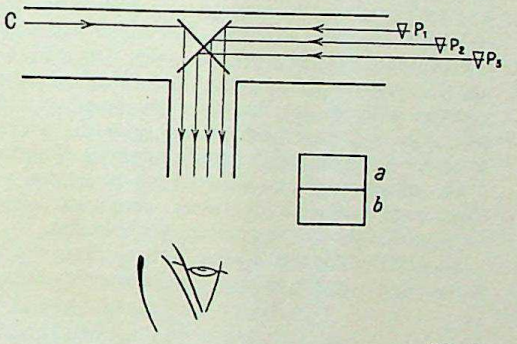


Fig. 1.
Schematic diagram of colorimeter
C, Light to be analysed.
P_1, P_2, P_3, primary light beam and independent modulating system.
a. Mixture of three primaries.
b. Light analysed in the photometric system or by the observer.

Three-colour vision All experiments so far carried out in the field of colour vision indicate that colour vision is essentially a three-colour phenomenon. The proof of this is obtained through colorimetric experiments (Fig. 1).

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

A colorimeter is a photometer enabling a coloured beam of light C to be compared with a beam made up by the addition of various proportions of three separate primaries: blue (P_1), green (P_2), and red (P_3). The two fields are balanced for intensity and hue by varying the amounts of the three primaries. We can then write:

$$C = aP_1 + bP_2 + cP_3$$

the sign = means visually equivalent to.

The coefficients a, b and c of the colours P_1, P_2 and P_3, are the co-ordinates of the colour C.

With another set of primaries, P'_1, P'_2, P'_3, that is, with an alternative blue, green and red, another colour equivalent is obtained with different coefficients:

$$C = dP'_1 + eP'_2 + fP'_3$$

These results show that the eye is an infinitely less discriminating organ to colour that the ear is towards sound. In other words, the eye will find colours similar though their spectral distribution curves are quite different.

Two colours C and C′ which have trichromatic co-ordinates a, b, c, a′, b′, c′, where:

$$a = a'$$
$$b = b'$$
$$c = c'$$

in the same system of primaries, are visually equivalent.

Thus it can be said that in practice any colour can be reproduced by a mixture of three primaries — red, green and blue. *The three-colour concept is fundamental in colour photography, for with no notable exception, all processes of colour reproduction whether additive or subtractive are based on this principle.* It is this trichromatic principle which explains the presence in colour materials of either a three-colour réseau in additive processes or three superimposed emulsions, each containing the appropriate dye, in subtractive processes.

Due to this characteristic of three-colour vision it is possible in the field of colorimetry to define a colour more simply and in a more practical way than in the physical field of spectrophotometry. In all colour specifications, three variables are used, either the dominant wavelenth, the intensity and the saturation or the three co-ordinates of the CIE system which will be described later.

These colorimetric systems will now be described in order to compare and understand the colorimetric considerations of colour reproduction.

Specification of a colour in terms of intensity, dominant, and saturation One of the first stages in colour definition was through the use of colour charts which were carefully chosen and bound in a handbook. In this field the best known handbook is that of Munsell which is widely used in many industries. Munsell's handbook contains 400 charts and the colours are arranged page by page with variations in intensity and dominant hue varying for example from yellow to blue, magenta to green, and red to violet. The use of such scales is not simple, for in order to identify a colour, comparison must be made with several charts and obviously to achieve satisfactory precision the observers must be highly skilled.

CIE System In 1931 the Commission Internationale de l'Eclairage introduced a more convenient system using three numerals which was the result of specialized work carried out in English and American laboratories. In this system colours are specified with reference to three co-ordinates using three convenient primary colours.

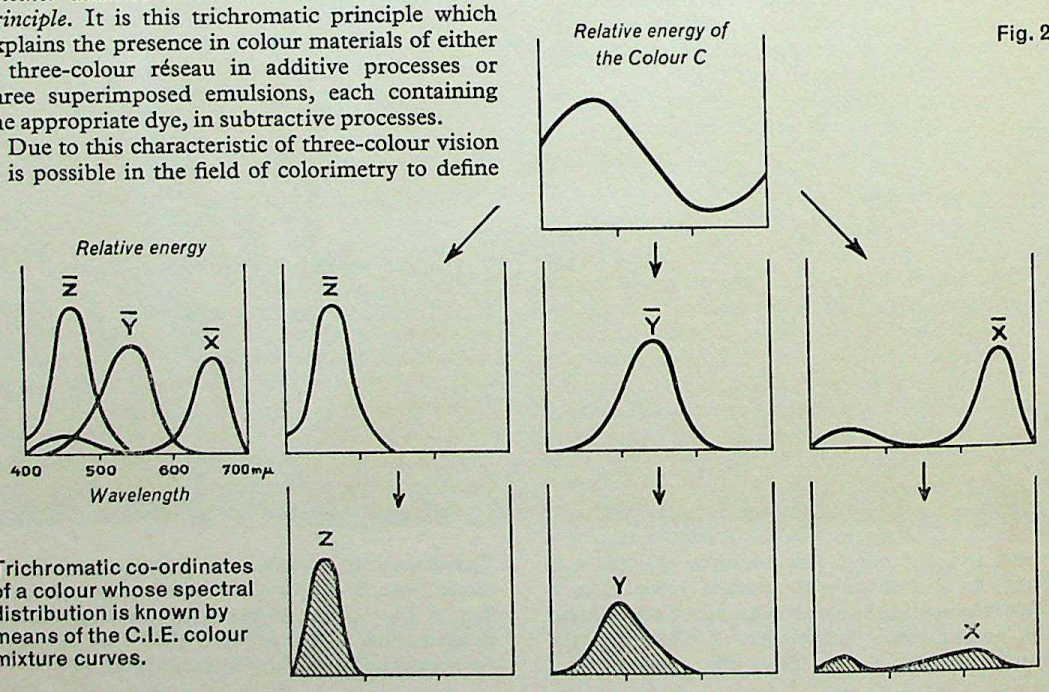


Fig. 2.

Trichromatic co-ordinates of a colour whose spectral distribution is known by means of the C.I.E. colour mixture curves.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Calculation of the CIE trichromatic coefficients and mixture curves One of the features of the CIE system of specifying colours is the ability to readily calculate the X, Y and Z co-ordinates of any coloured light from the spectral absorption curves and tables, without the length and unreliable visual measurement. The basis of the calculations are the CIE tables which give values of the mixture curves.

For a given intensity of each radiation these mixture curves express the quantities $\overline{X}_\lambda$, $\overline{Y}_\lambda$ and $\overline{Z}_\lambda$ for each of the three primaries of the International System, they are necessary to establish photometric balance (Fig. 2). Knowing the spectral distribution of the colour to be specified C_λ, and the three mixture curves, it can be seen that the trichromatic co-ordinates of the colour C are represented by the areas of the three curves obtained by multiplying, wavelength by wavelength, the respective ordinates of the curves C_λ and X_λ, C_λ and Y_λ, and C_λ and Z_λ (Fig. 2).

Mixtures of colours Having defined the physical properties of coloured light beams in the appropriate sections, it is of interest to describe the optical behaviour of coloured light beams particularly the aspects applicable to colour photography.

(*a*) *Additive mixtures.* The term additive colour mixture is applied to systems in which the colour impression is gained from the 'addition' at the retina of two or more simultaneous light beams. Additive colour experiments can be quite easily carried out using two or more projectors whose light is modified by the use of suitable filters (p. 33).

Complementary colours: Two colours are said to be complementary when their additive mixture gives a sensation of white. Common complementary colours are blue and yellow, green and magenta, and red and blue-green (cyan).

The same conclusions can be reached by the use of coloured sectors on a disc which is rapidly rotated. The colours are fused by the eye through a persistance of vision phenomenon (Newton's experiment).

(*b*) *Subtractive mixtures.* These mixtures are obtained, for example, by placing several superimposed filters in a light beam (p. 33).

Bearing in mind what has been said, each filter absorbs or subtracts a certain proportion of the light from the light beam, the transmitted light corresponding to the radiations common to the transmission curves of the filters present. Of particular bearing are the theoretical filters blue, green, red, yellow, magenta and cyan, corresponding to the spectral distribution on page 33. It can be readily seen with the following combinations:

blue + yellow = black
green + magenta = black

and that

red + cyan = black
magenta + yellow = red
cyan + yellow = green
cyan + magenta = blue

From what has been said previously it can be seen that the additive complementary colours give black when mixed together.

Application of the preceeding results to colour photography (additive and subtractive systems) It can now be shown how these simple principles of producing colours take their place in practical colour systems. In some additive processes three projectors may be used on which blue, green and red filters are fitted. Subtractive processes generally have the three images — cyan, magenta and yellow — superimposed on the same support.

Adaptation Bordering on the visual phenomena explained by colorimetric principles, there are many aspects of colour vision untouched by normal colorimetry and which are usually considered with the complex phenomena of adaptation (see *Vision*). Adaptation is particularly shown when white or neutral grey areas are considered (that is, areas whose reflection is substantially uniform throughout the visible spectrum). Under the most varied conditions of illumination (tungsten light, fluorescent lamps, daylight) these objects always have the appearance of being white or grey after a certain adaptation period. This effect is of major importance in photographing colours. As will be seen later, photographic emulsions do not possess this property of adaptation. If an emulsion has been balanced to render greys as grey with a light of colour temperature 3,400°K for example, it will give a blue rendering of the same objects when exposed in daylight; the daylight illumination is itself much bluer than the tungsten light.

Conversely, a film balanced for use in daylight will give pictures with an overall orange cast if it is exposed with tungsten illumination.

In theory it is therefore necessary to have emulsions available which are balanced to all types of illumination, but in fact manufacturers limit the types. There are two main ones — tungsten balance and daylight balance — and to a limited extent emulsions balanced for clear flashbulbs.

When exposure conditions depart radically from those specified a correction filter can be used over the camera lens to adjust the quality of the light reaching the film.

With colour systems involving a printing stage — e.g. negative-positive — the requirements of balance are less critical; with 'universal' colour negative stocks any light source can be used without correction.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

The problems of colour photography can therefore be stated as the means of conveniently modifying the amount of red, green or blue light in the case of additive systems or of cyan, yellow and magenta dye in subtractive ones.

It has been shown that colorimetry enables the quantities of the three primaries needed to produce a desired colour to be calculated from the mixture curves, and it is therefore possible to visualize the broad principles of an additive system based on this fact.

Additive processes It will be assumed that the three primaries for additive synthesis are provided by three projectors fitted with blue, green and red filters respectively to give light beams of known properties.

It must also be assumed that in previous work the mixture curves corresponding to the three primaries have been determined.

The final assumption is that three photographic emulsions are available whose spectral sensitivity can be adjusted to be equal to the three mixture curves respectively.

A test object is now photographed successively with each of the three emulsions. From these three negatives will be obtained which on printing gives three positives. If the work has been carried out correctly the transmission of the three positives in similar areas will be equal to the quantities of primary which are necessary to reproduce the corresponding area of the subject.

In other words the pictorial sequence shown on page 33 has been carried out photographically. To complete the process the three positives obtained are placed in the three projectors already mentioned and the colour reproduction of the object will be seen on the screen. From this experiment two important points emerge. The choice and quality of the synthesis primaries and the spectral sensitization of the plates used to make the initial exposures. If these two factors are linked in such a way that the three spectral sensitivities are exactly equivalent to the three corresponding mixture curves of the system, colorimetric principles show that the additive reproduction on the screen will be correct.

In the complete process the analysis which involves the spectral sensitivity of the plates and the mixture curves and the synthesis involving the quality of the primaries are regarded separately, though linked in a definite way.

Subtractive processes The subtractive processes are really a technological simplification of additive processes in the sense that the synthesis step of these processes is achieved in a more convenient way than by the additive system described above.

The analysis step is common to both.

In subtractive synthesis the three constituents of the colour image are no longer three black-and-white positives but are three monochrome images in cyan, magenta and yellow, placed one above the other. The reason for these three colours (see Colour) is that, as shown on page 29, they possess a spectral property of transmitting two thirds of the visible spectrum more or less completely and absorbing the remaining one third. One can say, for example, that yellow transmits green and red and absorbs blue, magenta transmits blue and red and absorbs green, whilst cyan transmits blue and green and absorbs red.

Suppose that by some convenient method the three monochrome positives in cyan, magenta and yellow have been obtained. These correspond to the red, green and blue primaries of the additive system. (For example the cyan positive which absorbs the red should have the same optical density to red light as the corresponding black-and-white positive to be projected by red light. If the black-and-white positives are replaced by the coloured positives using the additive projection system with its filters, the same result will be obtained as for normal additive projection.)

However, it is possible to simplify this system considerably. Take the three coloured positives, superimpose them and illuminate them by the mixture of the additive primaries (blue, green and red); in other words by white light.

The cyan image will allow the blue and green light to pass without modification; only the red will be affected. With the magenta image the red light together with the blue will pass freely and the green will be modified. Finally the yellow image will transmit the green and red light, and the blue will be modified.

Following on this description of the properties of the three monochromatic images it can be seen that when the three are superimposed and examined by evenly transmitted white light, the same result will be obtained as with additive projection — a correct reproduction of the colours.

From the viewpoint of colorimetric theory the additive and subtractive synthesis systems are really two different ways of obtaining the same result. The analysis principle is common to both systems and although there are material differences between the two systems at the synthesis stage the colorimetric principles of synthesis are identical.

In the sections describing particular processes, both additive and subtractive, it will be seen that colorimetric principles provide a general framework. The differences occur because of the necessity for overcoming practical difficulties — spectral sensitivities of the emulsions falling short of the ideal or, particularly with subtractive processes, imperfect spectral characteristics of the image dyes. These differences, together with the

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

basic failure of the photographic process to behave in the simple way which has been assumed, mean that the colour rendering in the photograph will be only an approximation which will vary from one process to another; these will be indicated in each particular case.

COLOUR

PHYSICAL AND PHYSIOLOGICAL ASPECTS OF COLOUR

(See *Light* and *Colour Vision*)

The classic experiments described in the section on light show that colours, or coloured radiations, consist of a large number of simple radiations which can be separated by means of a suitable dispersing system. This may be a prism of glass or other refracting substance or a plate whose surface is covered with a finely engraved line grating; these disperse the light by refraction and diffraction respectively. The different radiations extend from blue through to red encompassing all the intermediate hues which go to make up the 'visible spectrum' — that is the range of electro-magnetic radiations to which the eye is sensitive.

It should be noted that beyond the blue and the red there are other radiations, the nearest being the ultra-violet and the infra-red. These are not detected by the eye but can be recorded on suitable photographic plates and by other methods.

Prisms and diffraction gratings are used in apparatus which analyses a given light beam either qualitatively (spectroscope) or quantitatively (spectrograph or spectrophotometer). The wavelength and intensity of the dispersed light enable a 'spectrophotometric curve' or 'spectral characteristic' to be produced; this can completely define the colour properties of the light beam.

When the range of radiations are substantially equal in intensity the eye has the sensation of 'white light'. On the other hand when certain wavelengths predominate the light will generally have a hue corresponding to the colour of the predominating radiations. Fig. 1 illustrates this; the major part of the radiations in red light have a wavelength between 600 and 700mμ; with blue light it is 400 to 500 mμ, and 500 to 600mμ for green light (see *Light* for definition of wavelength).

The light reaching the eye is always the product of two factors — the incident light or illumination and the properties of the object which modify in a fixed way the light which is reflected or transmitted. To study exactly what is taking place in any particular case it is necessary to know both the spectral characteristics of the light source and the transmission or reflection characteristics of the various materials.

The reflection or transmission characteristics of materials can be defined under certain conditions by using suitable methods. These characteristics are peculiar to the material and they enable a theoretical prediction to be made of the colour which will result when the material is illuminated by a light source of given spectral composition.

Illuminants Both natural and artificial light sources in general have a well defined spectral composition. Sunlight in particular has been systematically analysed and typical curves have been obtained by specialist laboratories.

As for artificial sources, these may be either incandescent or luminescent.

The incandescent sources are solid bodies which have been raised to very high temperatures by a suitable system — for example by an electric current which by means of Joule's effect raises the temperature of a tungsten wire. The theory of the light emission by bodies at very high temperatures was first enunciated by the German physicist Max Planck and it is Planck's law which predicts with fair accuracy the light emission of an incandescent body. Incandescent bodies have a characteristic continuous spectrum and generally the colour of the light changes from red to blue as the temperature is raised; at the same time the total energy dissipation of the system increases. The red colour which is emitted corresponds to the well-known phenomenon when a metal is heated becoming

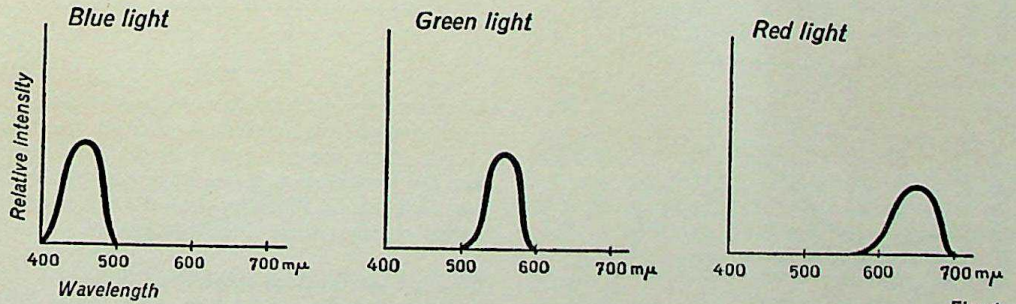


Fig. 1.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

first a dull red; the blue colour is exhibited by incandescent sources at very high temperatures such as the craters of carbon arcs. As a first approximation the temperature to which an incandescent body is raised will define the spectral composition of the light emitted and the accuracy will improve as the laws applying to Planck's integral radiator or ideal solid are more closely adhered to.

The colour temperature gives a rough guide to the colour quality of the light emitted by an incandescent body. As an example, sunlight, which can be considered as the emission of an incandescent body, has a colour temperature in the neighbourhood of 5,400°K. Practical incandescent light sources use a tungsten radiator, and as shown by Forsythe, emission characteristics can be deduced from Planck's law. The incandescent lamps which are used photographically have temperatures ranging from 2,800°K to 3,400°K. It is difficult to obtain temperatures greater than these as tungsten melts at about 3,500°K. The comparison of these temperatures shows why tungsten light always appears more orange than sunlight when a side-by-side observation can be made.

The luminescent sources consist of gas or metallic vapour through which an electric current is passed. Under these conditions luminous radiations are emitted which are determined by the nature of the gas or vapour which is excited. These radiations have a discontinuous spectrum sometimes called a line spectrum and this may be to some extent accompanied by a continuous spectrum due to thermal emission or incandescence. Sometimes this luminescent emission consists only of a few simple radiations. For example the orange sodium line (which is, in fact, two closely spaced lines) is present in the visible spectrum to the virtual exclusion of any other. In practice the luminescent sources are rarely used as illuminants. Mercury vapour tubes for example emit several lines in the visible section but a greater part of the emitted energy is concentrated in the ultra-violet and is therefore invisible. By means of the phenomenon of fluorescence (q.v.) the energy present in this part of the spectrum is converted into visible light which may be pink, yellow or blue according to the type of fluorescent powder which is deposited on the inner surface of the tube. It is in the form of fluorescent sources that the luminescence phenomenon is used in practice.

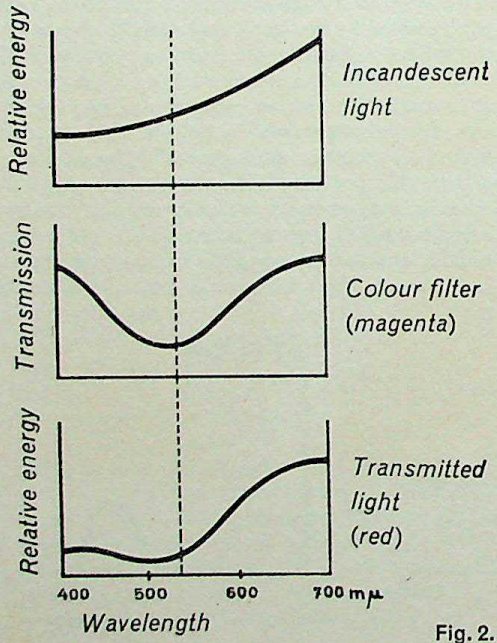


Fig. 2.

Transparent substances Transparent substances — coloured glass, filters for scientific or industrial use — have the property of allowing light to pass through them. The incident light may be appreciably modified during its passage through the substance depending on its nature. Coloured transparent materials absorb selectively certain spectral regions of the incident light. If a filter is red it is because it absorbs from incident white light the majority of the blue and green radiations and only transmits the red ones, which pass through to the eye.

Still in the field of physics a particular filter can be defined by a spectral transmission curve which is one of its principal characteristics. The spectral transmission characteristics of a filter can be found with the aid of a spectrophotometer by measuring the ratio of incident to transmitted energy at a large number of closely spaced wavelengths. (See below, Beer's Law.) This curve enables mathematical calculations to be made on the quality of the light transmitted by the filter,

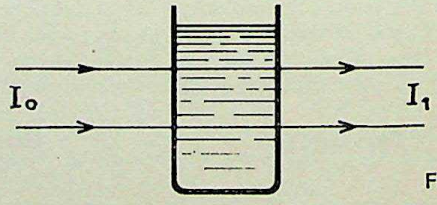


Fig. 3.

whatever the conditions of illumination, by mathematical combination, wavelength by wavelength of the spectral quality of the light source and the transmission of the filter (see Fig. 3). It can therefore be seen that the colour of the filter varies with the nature of the light source.

Beer's Law: optical density of filters.
Determine the absorption of a liquid filter

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

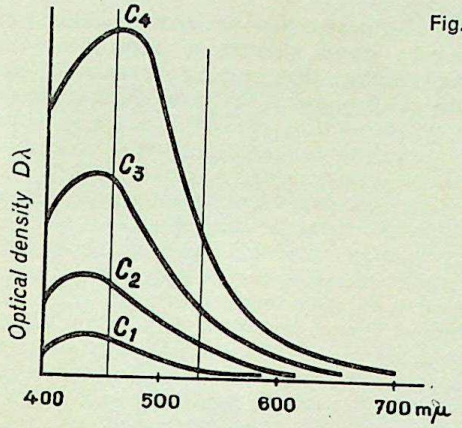


Fig. 4.

consisting of a solution of a dye in a cell of fixed size; then vary the concentration of the dye in solution in the cell. The results demonstrate a law which is followed in general by most dyes using monochromatic light; this is Beer's Law. Before expressing it, it is necessary to define the optical density of a filter. First, the transmission of the filter is expressed as the ratio of transmitted and incident light:

$$T = \frac{I_t}{I_o}$$

This ratio must always be less than unity. It is said that a filter transmits 10 per cent of the light or that it has a transmission of 10 per cent. The opacity is the reciprocal of the transmission, that is, the ratio between the incident and transmitted light:

$$O = \frac{I_o}{I_t}$$

The density of a filter is expressed as the logarithm of the opacity:

$$D = \log O = \log \frac{I}{T}$$

Beer's Law states that the density D_λ of a filter to light of a given wavelength λ is proportional to the concentration C of the dye from which the filter is made. It can be expressed as:

$$D_\lambda = k_\lambda C$$

The constant k depends on the filter and on the wavelength. It is the coefficient of extinction and increases as the absorption of the dye at the given wavelength increases. As an example, Figs. 4 and 5 show the spectral densities D_λ of a yellow dye at four concentrations. It can be seen that the constant k_λ is higher in the blue than in the green or red spectral regions. k_λ is expressed by the slope of the straight line which shows the variation in the optical density D as a function of the concentration C of the dye.

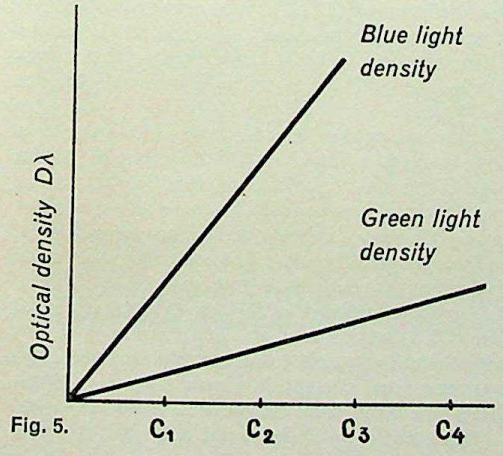


Fig. 5.

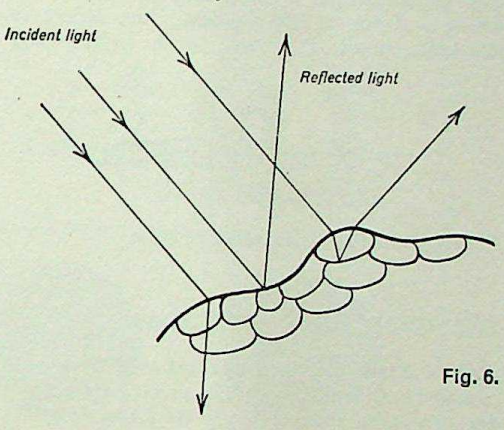


Fig. 6.

Reflecting materials The majority of our surroundings are made up of reflecting substances. The reflection of light by objects is the result of a complex mechanism through which part of the incident light is reflected, as by a mirror, from the object; another part of the light passes over the surface of the object to be re-emitted in random directions; finally the remainder is absorbed by the body. The characteristics of a reflecting body must take into account the absorbed fraction, the specularly reflected fraction and the fraction which is reflected after superficial absorption (Fig. 6). It is therefore a less simple process than that of transmitting materials.

The quality of the reflected light and its intensity therefore depend to a great extent on the nature of the reflecting surface — matt, polished, rough, etc — and on the angle of incidence of the light. Within certain limits a coefficient of reflection can be given to reflecting surfaces. Like the coefficient of transmission, it expresses the ratio between the reflected light and the incident light at a given wavelength, angle of incidence and angle of reflection, bearing in mind the previous remarks. To complete the characterization of the properties of a reflecting body to a luminous source the spectral reflection curve can be deter-

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

mined by computing the variation in the coefficient of reflection at all visible wavelengths. Here again, direct calculations can be made from the spectral distribution of the light source and the spectral reflection curve of the material to indicate the quality of the light which will reach the eye after reflection. Again, an object appears blue simply because of the combination of the absorption of red and green light and the selective reflection of the blue.

Diffusion phenomena The idea of diffusing surfaces is considered in the section on light. Diffusion of light by both reflecting and transmitting substances is a general phenomenon by which a beam of light striking the object is scattered in all directions. With transmitting objects an appreciable part of the incident light generally passes through in substantially the same direction. With matt reflectors the diffusion is far more complete. Under certain conditions it is possible to define the diffusion characteristics to give an impression of both the geometry and intensity of the emergent beam (Figs. 7 & 7a).

The length of the arrow represents the relative transmitted energy for each angle.

A study of diffusion is complicated by the fact that some radiations may be only slightly diffused whilst at the same time others are more strongly diffused. In such cases the colour changes according to the direction in which the light source is observed. This can occur, for example, with certain gelatin solutions which are yellow when looked *through* but blue when looked *at*.

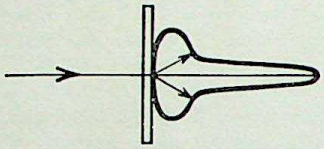


Fig. 7.

Partially diffusing transparent medium.

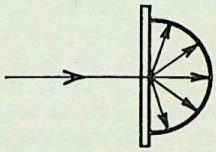


Fig. 7a.

Perfectly diffusing transparent medium (ground glass).

COLOUR CINEMATOGRAPHY

Colour films for commercial exhibition If amateur and professional film-making techniques are compared independently of format, certain similarities are noted in black-and-white work, particularly in exterior photography. With colour, on the other hand, the problems presented to amateur and professional and their solutions differ greatly.

The sharpness, the image quality and colour reproduction are influenced by the more complex methods required in commercial films for the following reasons:

Firstly the amateur usually requires only one positive copy and therefore uses a reversal material. Other copies can be made with a reversal duplicating film.

On the other hand in the commercial cinema between 10 and 100 copies are required and it is therefore necessary to use an original negative from which prints are made.

The first problem is the question of definition.

The definition must be constantly improved as the use of larger screens becomes more widespread.

The resolving power, or definition, of integral tripacks is inferior to that of black-and-white materials. The latter comprise only one emulsion layer whereas colour materials have three layers. In other words the image sharpness deteriorates slightly in each succeeding emulsion layer.

This defect is present in the negative and is increased still further during printing.

The manufacturing method in which the image order is changed so that the colours which contribute most to sharpness are on the surface has resulted in considerable improvement.

These problems do not concern the amateur as the definition of a reversal original is adequate.

The first objective of the professional is to obtain very consistent quality which must not suffer during multi-stage laboratory work.

The aim must be lenses with optimum correction, of large aperture yet adequate depth-of-field. A camera capable of showing the precise field-of-view together with the exact focus is essential; cameras of this type are now available.

At the same time other factors which influence the image quality must be taken into consideration — composition, lighting, colour distribution and contrast.

It should not be forgotten that each scene in a film is inseparable from its neighbours. Strict control over colour balance is essential; this is not too difficult when artificial lighting is used in the studio but natural lighting presents great problems.

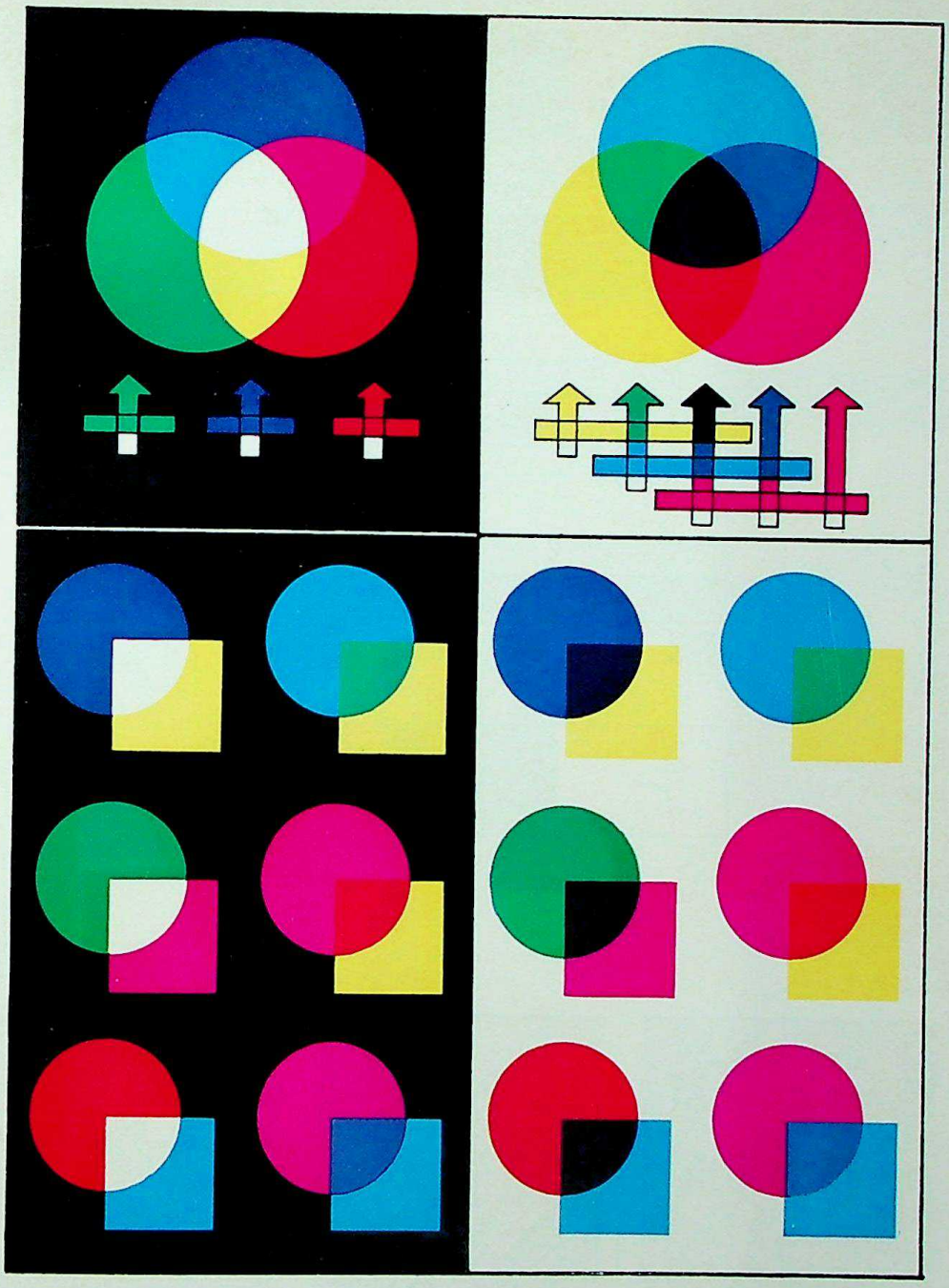
Two artificial lighting systems are widely used — arc lamps and incandescent lamps.

Most professional emulsions are balanced for use with tungsten filament lamp run at a colour temperature of 3,200°K. For exteriors or with high intensity arcs, correction filters are used. Spotlights are fitted with lamps of 1 to 10 kilowatts.

The lighting level varies not only with the pro-

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

COLOUR MIXTURES



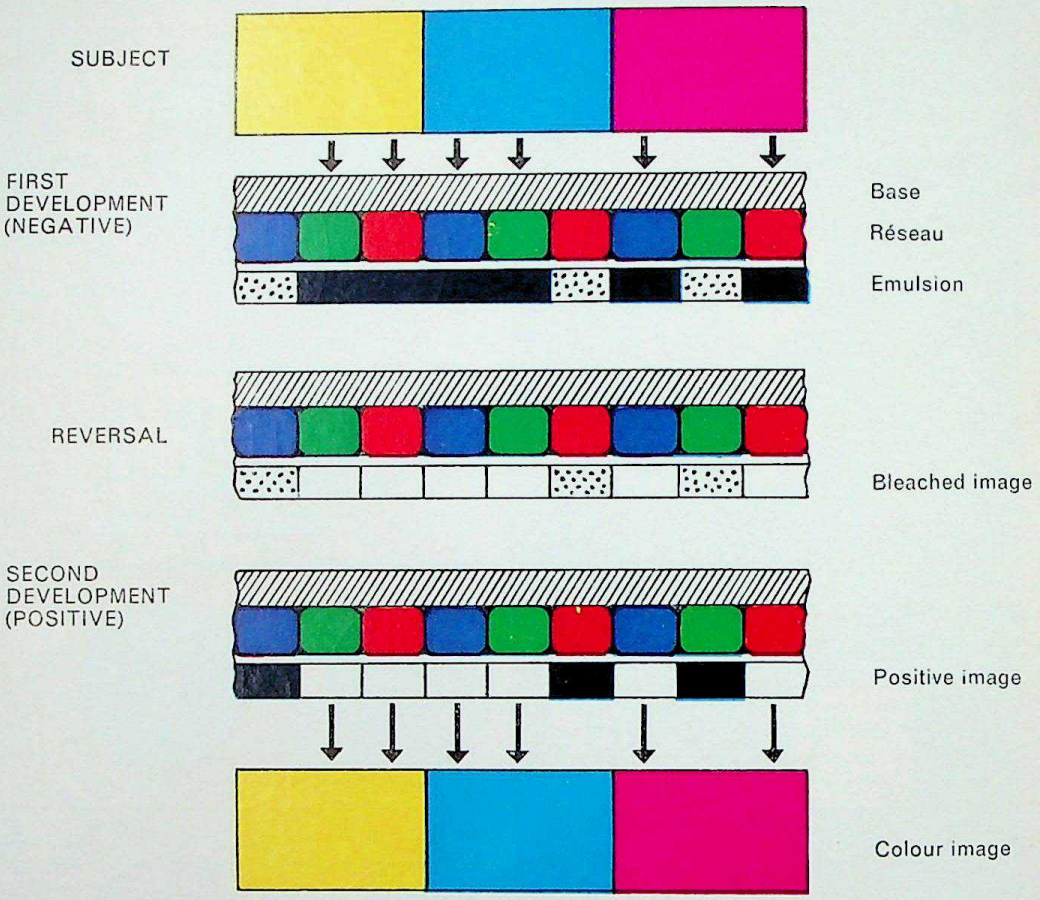
ADDITIVE MIXTURE

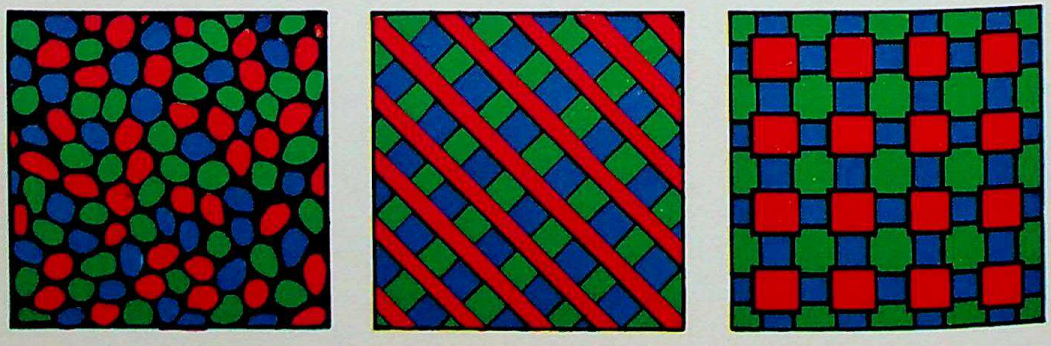
SUBTRACTIVE MIXTURE

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

ADDITIVE PROCESS

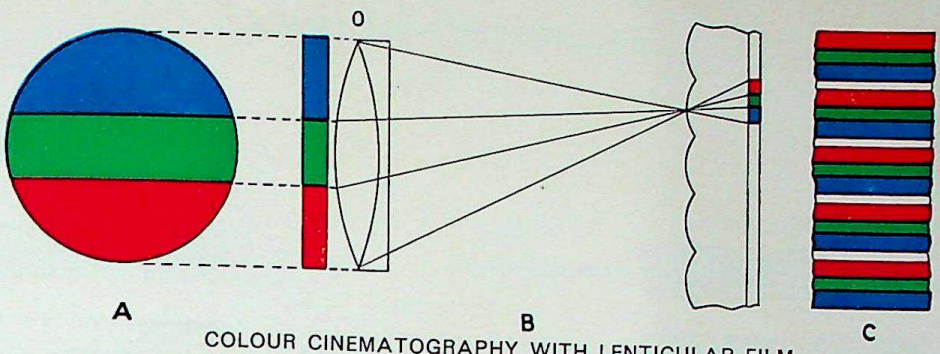
SCHEME OF PROCESSES USING
MOSAICS AND RESEAUX





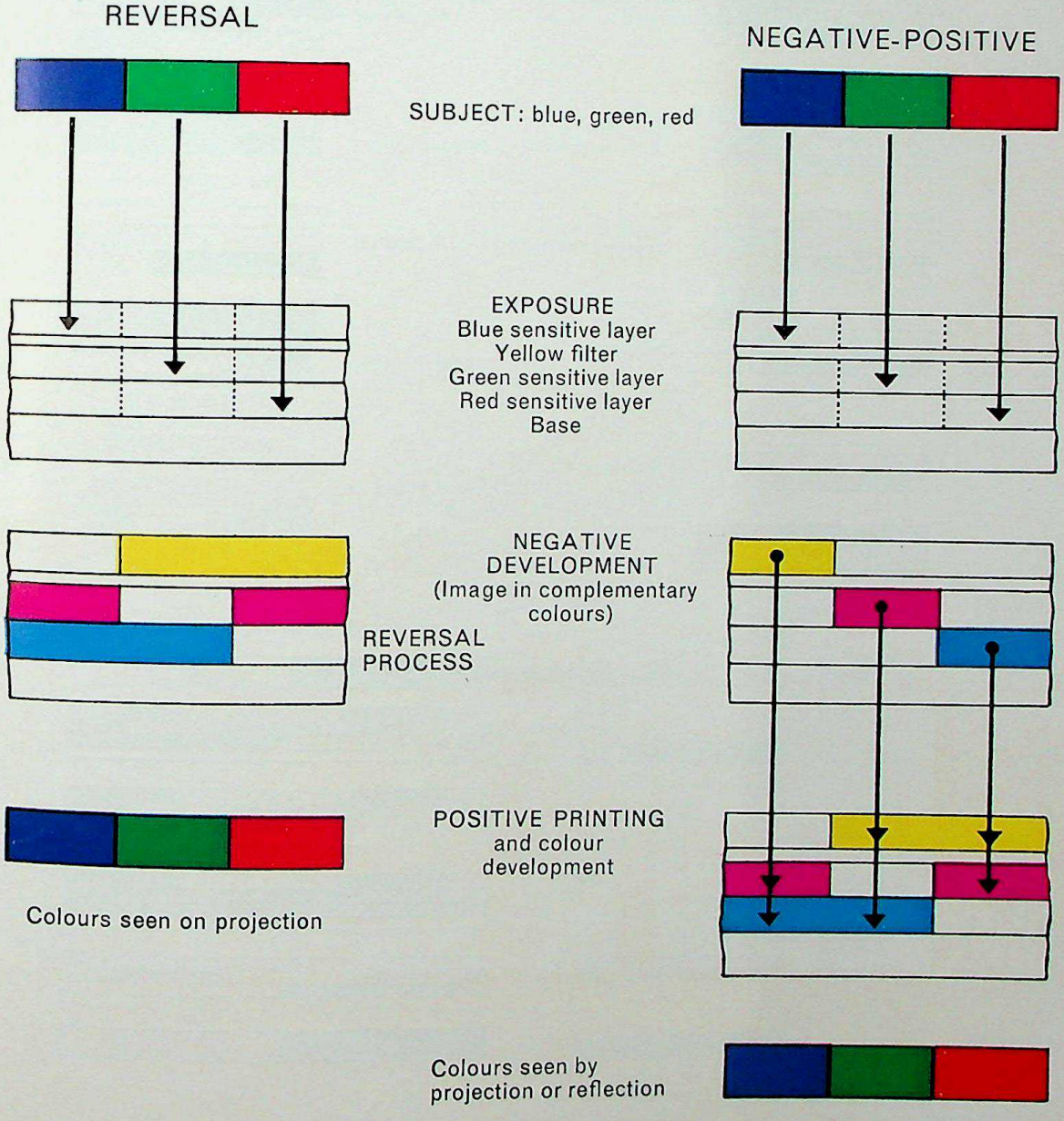
LUMIERE DUFAY COLOR JOHNSON (FINLAY)

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



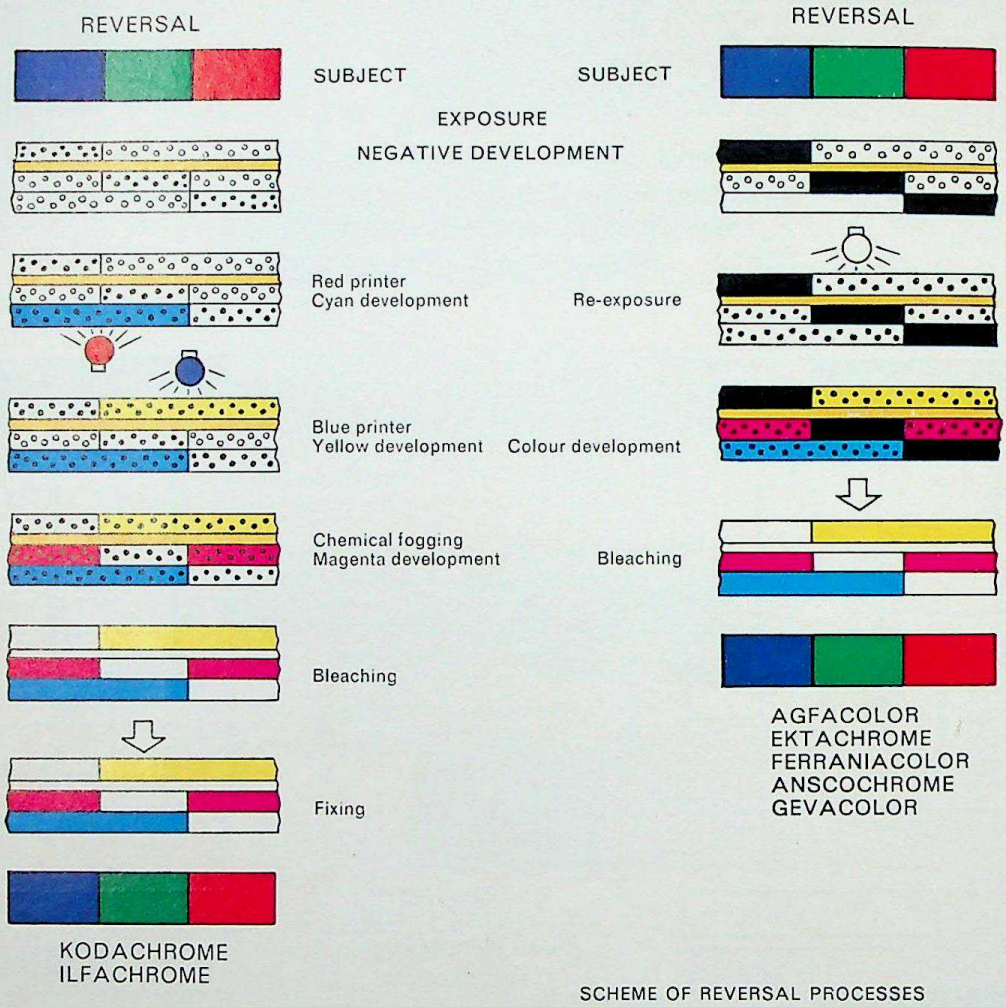
COLOUR CINEMATOGRAPHY WITH LENTICULAR FILM
A, the filter, O, the lens, B, the path of light through the lenticular film
C, the bands on the film corresponding to the different colours.

SUBTRACTIVE PROCESS

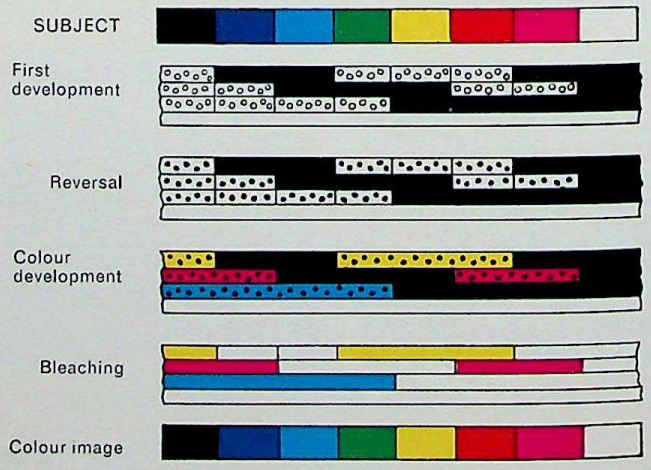


CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

SUBTRACTIVE PROCESSES

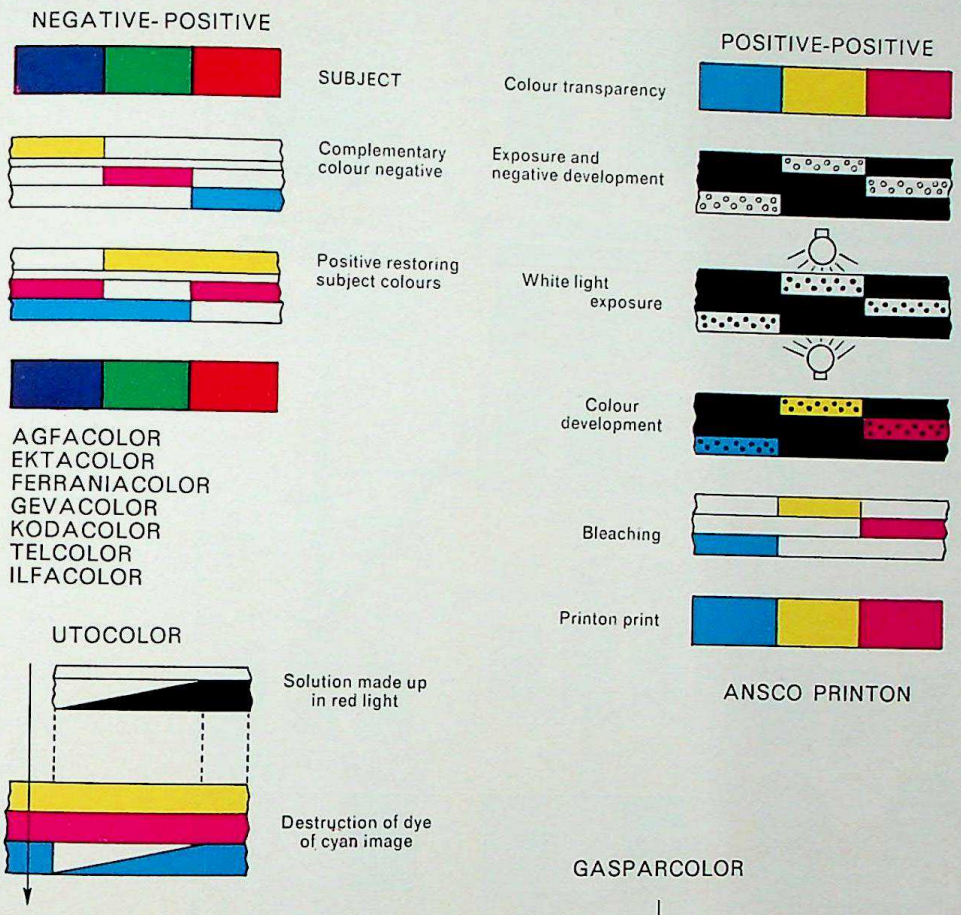


SCHEME OF REVERSAL PROCESSES



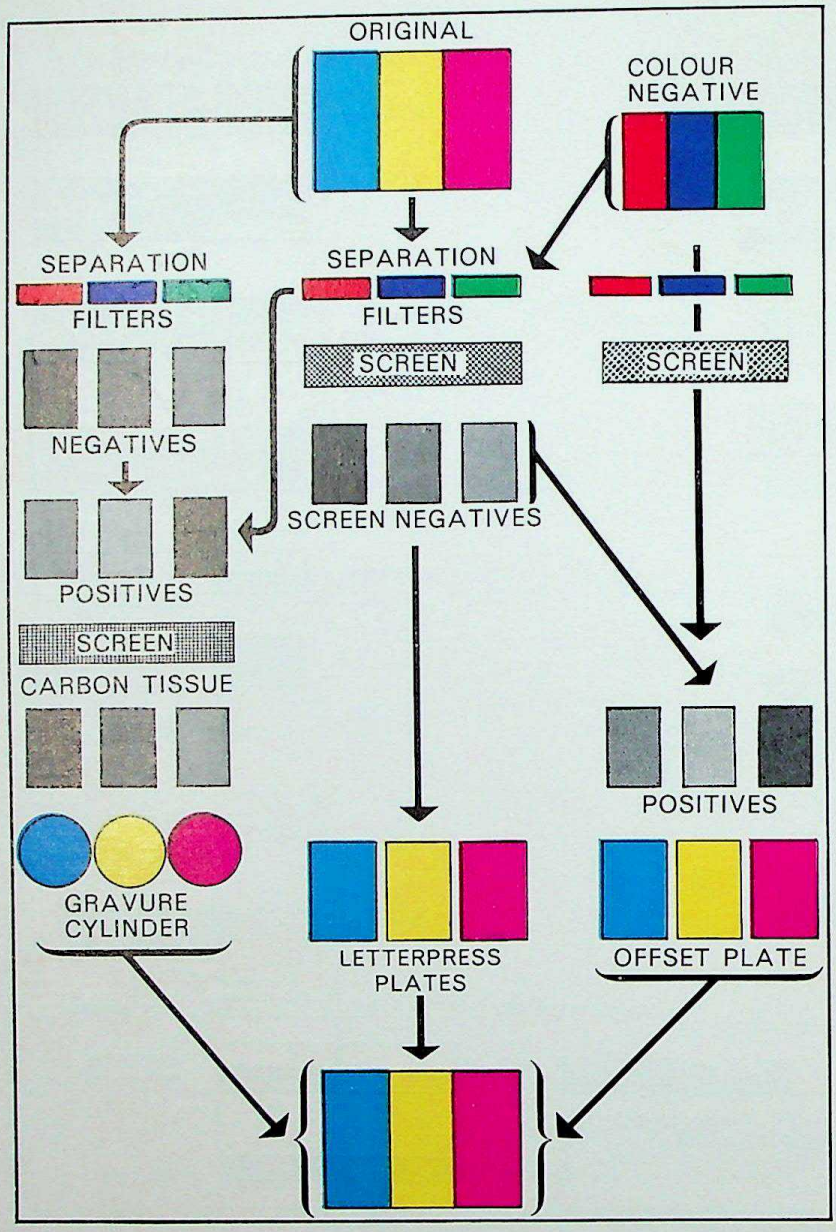
CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

SUBTRACTIVE PROCESSES



CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

DIRECT SEPARATION

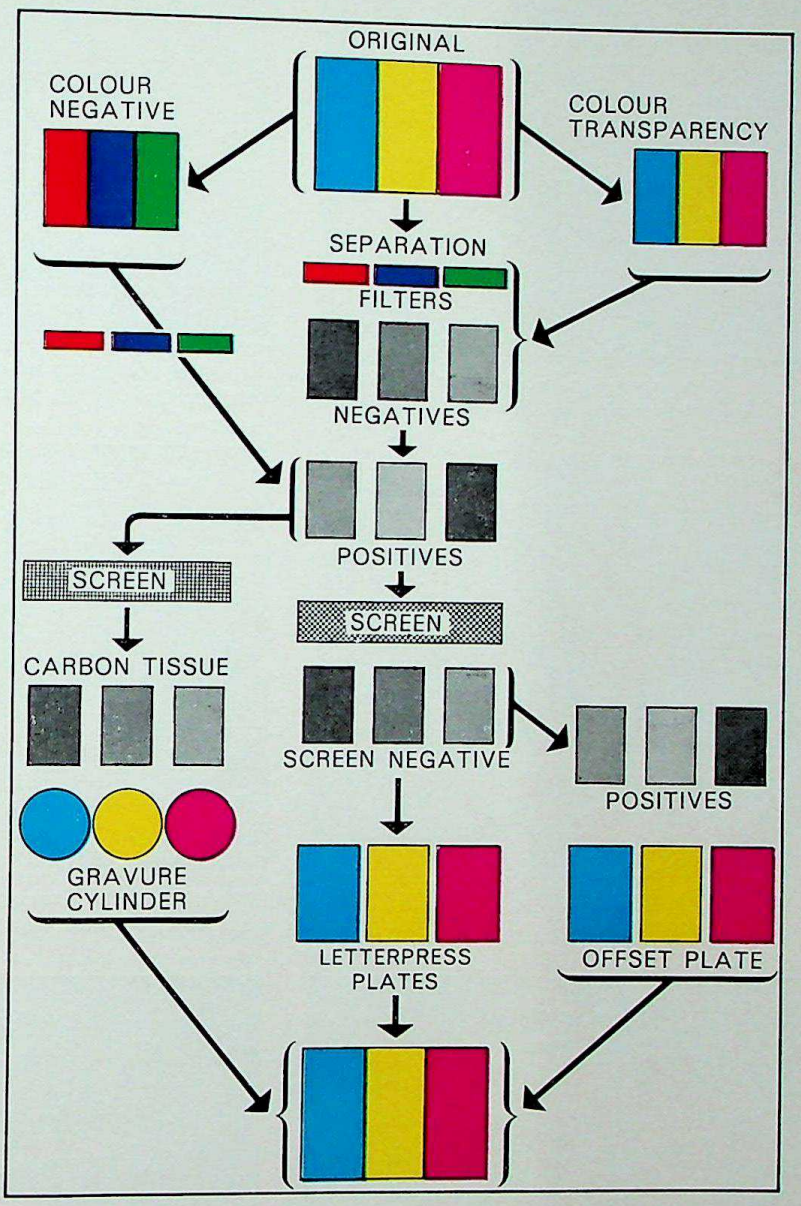


Centre: Separation screen negatives for producing either negative reliefs or, on the right, positives for the production of offset plates.

Left: Unscreened separation negatives and positives from which three negative images are printed on carbon tissue which are then simultaneously stripped and given a gravure screen.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

INDIRECT SEPARATION

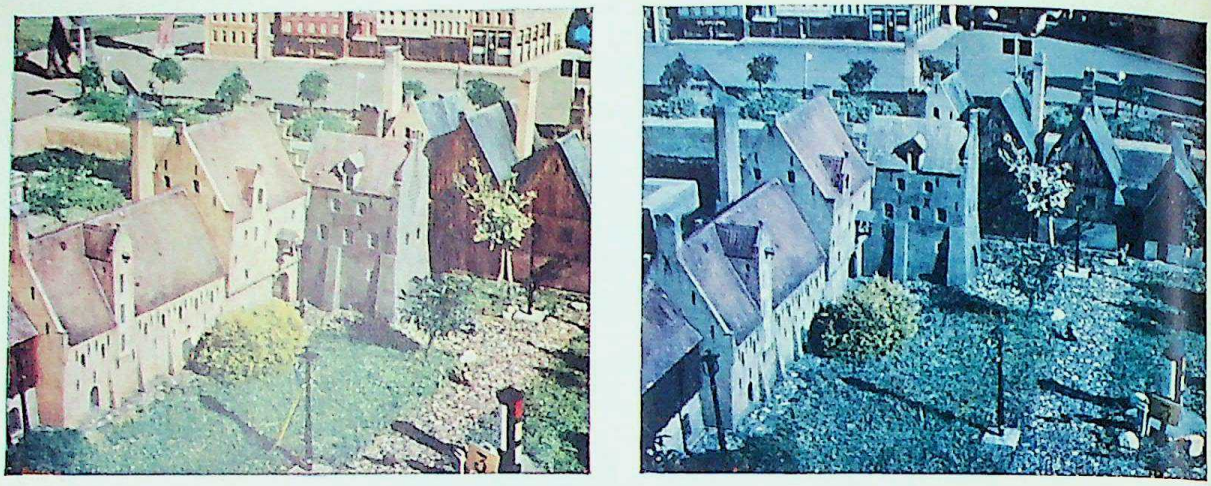


Centre: Separation negatives on continuous tone emulsion, printing of positives to obtain either three screen negatives or three printing plates or offset positives.

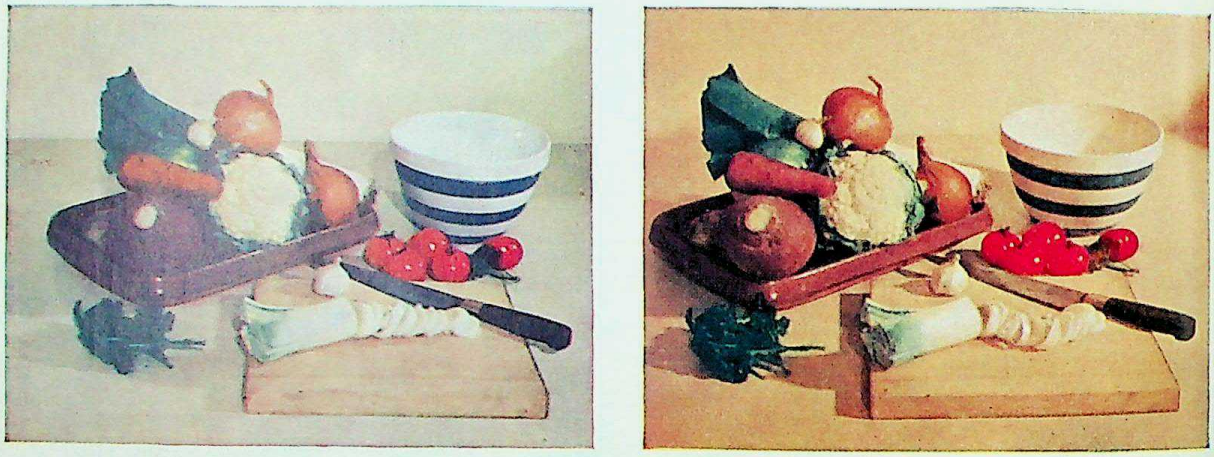
Right: Same procedure starting from a transparency.

Left: From an original colour negative, one can make either three separation positives for which gravure carbons can be printed or screen negatives for half-tone (centre) or offset positives (right).

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



Two exposures of a scene in daylight showing normal colour rendering with daylight-type film, and the blue, moonlight effect of using Type A film without a filter.



Two exposures of a subject lit by Photoflood lamps of 3,400°K, showing normal colour with Type A film and the yellowish effect obtained with daylight-type film.

Neon signs and street scenes at night will usually give acceptable results on any type of colour film. These pictures of Piccadilly Circus were taken while there was still a little daylight in order to obtain some detail and outline of the buildings.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

cess but also with the requirements of wide-screen processes. The definition necessary in wide-screen processes, together with depth of field requirements, may demand a level of 800 ft. candles.

Recent experiments have shown that arcs can be used with these emulsions without special filters thanks to the introduction of special carbons. This can be extremely useful when large scenes have to be lit, but it should be noted that these special arcs do not give exactly the same light quality as incandescent lamps.

Although the professional will have the most advanced studio and laboratory techniques at his disposal this is not enough for the production of quality results; artistic considerations make a major contribution to the final result.

There are many important questions which have a bearing on the production of a successful colour film. Should the rules governed by theoretical and technical considerations be followed absolutely or should artistic impulses be given a free rein ?

Studio lighting in particular gives examples of this conflict.

In theory certain lighting ratios must not be exceeded or colour rendering will suffer. The essential feature of lighting, however, according to some producers, is to produce a balance of highlight and shadow which will give the required dramatic effect.

They maintain that it is wrong to be cramped by the theoretical rules.

Deep shadows should not be avoided simply on the grounds that they will not be correctly reproduced.

Following the technical rules of balanced lighting will undoubtedly give impeccable colour reproduction but there may be less artistic interest.

To obtain the desired results, prior experience is the best guide to the selection of the method used. The professional touch is only achieved by the continuous collaboration of a harmonious production team.

This must be applied to all the departments concerned — sets, costume, make-up — and all other factors which at the same time bring in technical and aesthetic considerations.

The professional has one great advantage over the amateur; this is the possibility of correction during the making of prints.

By this means the density and even the key of the image can be controlled. Printing correction obviously favours certain effects but is not without its limitations. The correction of certain image characteristics inevitably results in losses in other directions.

Take for example a colour correction in which the redness of a face is reduced to give a more natural colour. To do this cyan is added to the print giving the required effect on the flesh tones but at the same time an unwanted blue-green cast may be given to the shadows. It is therefore at the camera stage that the desired balance should be obtained.

It is interesting to note in this context that it is difficult to judge a scene independently of the preceding one. Colour vision and accommodation effects must be taken into account.

For example, a scene will appear more yellow if the preceding one was blue. This same scene will appear more natural if the preceding scene was yellowish.

The balance of each scene must be related to those adjoining it. This is obviously of prime importance when applied to successive scenes shown on the screen. The matter is further complicated by the fact that colour of the projection light may give a warm or cold cast to the image.

To produce a scheme for a complete production all the technical points must be sufficiently familiar to enable the required artistic results to be produced without the technique being obvious. The success of the completed colour film depends on the ability of the technicians to achieve this end.

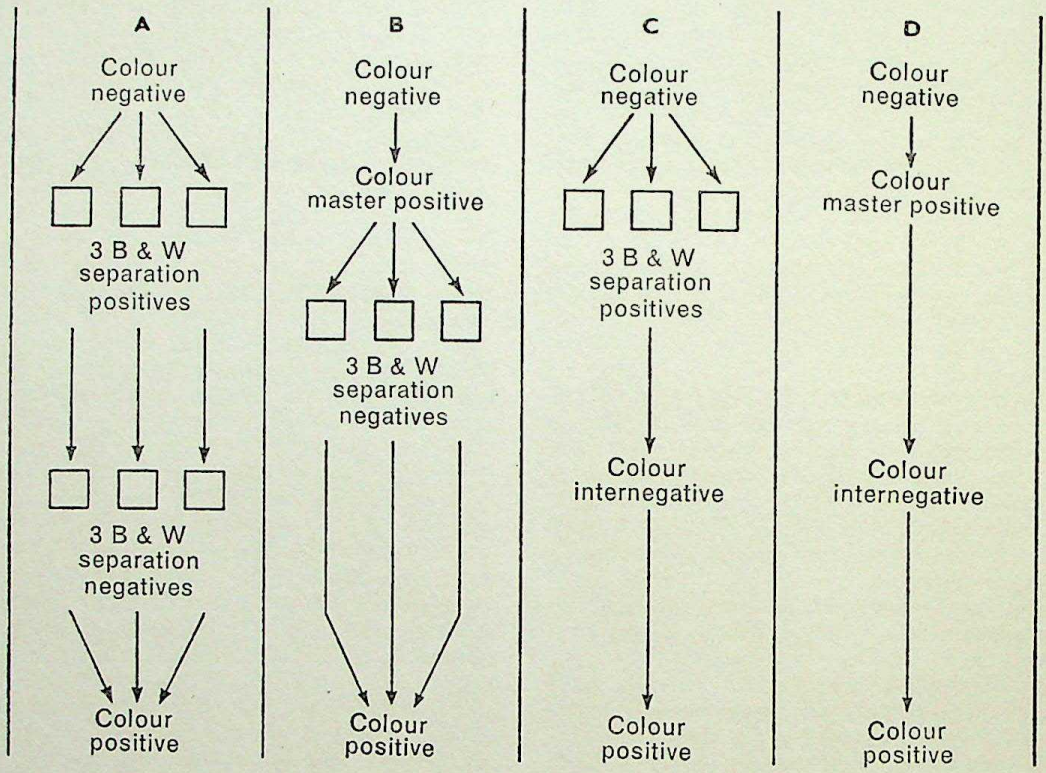
COLOUR CINEMATOGRAPHY (Commercial processes)

In putting a colour motion picture process on the market it is essential, as in black-and-white, that intermediate stages between the original camera film and the distributed print are used so that special effects can be incorporated into the print. Even when these special effects are not essential a master copy must be obtained which can be used if the original is damaged. When the camera original is a multi-layer colour film several alternatives can be used as shown in the diagram over page.

In the first method (A), black-and-white negative and positive materials are used in the intermediate steps. In the systems (B) and (C), a multi-layer film is used in one of the intermediate stages and black-and-white film in the other. In process (D) the films used in both of the intermediate steps are multi-layer colour films. A great number of technical and economic factors must be taken into account when deciding which process to use, for each process has its merits and demerits. Process (A) is too complicated for general use as it is necessary to print from black-and-white separations at both stages. Method (B) is also complicated because the final colour print is made by triple printing from black-and-white separation nega-

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

tives. Method (D) has the disadvantage that no black-and-white stage is used, therefore there is no protection against storage changes manifest in colour film; furthermore it has not definitely been proved that such a system can yet give the required quality. In method (C) certain disadvantages associated with the other methods are avoided and this would seem the most suitable process for general use. It is on these lines that the Eastmancolor and Gevacolor processes have been developed. With Agfacolor and Ferraniacolor an interesting variation on method (B) is used in which the duplicate negative is made on a reversal material (see also Technicolor Process.)



COLOUR DEVELOPERS

There are two basic types of colour developing agents:

1. the p-aminoaniline derivatives
2. the p-aminophenol derivatives

These compounds react with couplers (q.v.) via their free amino groups, hence one of the amino groups of the p-aminoanilines, and the sole amino group of the p-aminophenols, must be unsubstituted.

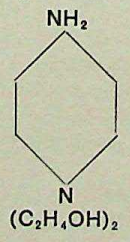
The solubility and instability of the dyes obtained using p-aminophenols have excluded these compounds from practical use.

The p-aminoaniline derivatives are obtained by introducing substituents into one of the amino groups and also by introducing substituents into the benzene nucleus.

The presence of particular substituents may influence the activity and diffusibility in the emulsion layer, and after colour development may affect the solubility, stability and colour of the resulting dyestuff; the toxicity of the developing solution may also be affected.

The p-aminoaniline derivatives are liable to cause severe dermatitis when in direct contact with the skin; individuals may become more susceptible to this over a period of time.

Many patents have been issued on methods of reducing this effect, usually by reducing the oil solubility of the compound, for example:



CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

PRINCIPAL COLOUR DEVELOPING AGENTS IN CURRENT USE

CHEMICAL NAME	COMMERCIAL NAME	MANUFACTURER	USE
2-amino-5-diethylamino-toluene monohydrochloride	CD2	Kodak	Eastmancolor positive
	Tolochrome	May & Baker	
β-methylsulphonamidoethyl ethylaminotoluidine sesquisulphate	CD3	Kodak	Eastmancolor negative
	Mydochrome	May & Baker	
p-diethylaminoaniline sulphate	Paramine	Gevaert	Ektachrome Negative and Positive
	TSS	Agfa	
	Activol S	Johnsons	
p-diethylaminoaniline hydrochloride	Activol H	Johnsons	Negative and Positive
p-diethylaminoaniline SO_2 addition compound	Genochrome	May & Baker	Negative and Positive
	Activol	Johnsons	
p-hydroxyethyl ethyl aminoaniline sulphate	Activol X	Johnsons	Negative and Positive
	Droxychrome	May & Baker	
	F41	Ferrania	

COLOUR IMAGE QUALITY

The control of colour image quality is an attempt to express a subjective impression in objective terms.

Subjective phenomena	*Objective phenomena*
Colour quality	Colour rendering
Modelling	Tone separation
Image smoothness	Graininess
Sharpness	Resolution

COLOUR RENDERING

A. Subjective aspect There are many factors involved in the subjective impression of a colour photograph, mainly because of the difficulty in comparing the original and the colour photograph. Some prints may be very pleasing despite their colour rendering being inaccurate; colour variations can be measured by colorimetric methods. Only experience can indicate the extent to which these variations can be tolerated and which colours are the most difficult to reproduce.

1. Some colours, such as skin tones, green foliage or the blue of the sky, are very critical owing to their predominance and relative brightness.
2. There is however a degree of colorimetric tolerance in these tints before the results cease to be satisfying or become garish.
3. Greys must be reproduced by a substantially neutral colour otherwise the whole print will have an unnatural cast.
4. A general colour cast (red, green, blue, etc.) will be most apparent in the neutrals and the overall colour contrasts will be reduced. All colours, except grey, will tolerate a certain colour shift without losing their natural appearance. This effect will be more noticeable if all the colours of the print have the same colour cast. In practice the structure and handling of integral tripack three-colour subtractive materials makes the possibility of colour casts particularly great. Any lack of balance in the camera material itself, in the exposing conditions (e.g. incorrect colour temperature) or in processing, can produce such a cast resulting from an excess or shortage of one image colour (giving a cyan, magenta or yellow cast in the case of excesses or red, green or blue casts in the case of shortages).

From the point of view of ease of control, photomechanical printing from three-colour plates is much more straightforward, particularly when a fourth black or key image is used to make the high densities more neutral and add body to the print. Colour casts will become less apparent on prolonged viewing due to the adaptation phenomenon.

Adaptation is particularly apparent when the object viewed is surrounded by an even neutral tint, for example when viewing a slide projected on to a screen in the dark. This means that a cine film having a number of scenes each with the same colour cast will not be noticeably off-balance after being viewed for a short period. A paper print is not subject to adaptation effects to the same extent for in this case there is an immediate comparison with known surrounding objects. On the other hand, in a cine film it is very unpleasant if varying scenes in the same film have differing overall balance even though each scene may be a close approximation to the original. It is a colour grader's job to balance successive scenes

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

so that independently they are acceptable yet in sequence produce no violent scene-to-scene changes.

B. Objective aspect The colour rendering is influenced by several technical characteristics in the make-up of the colour film — spectral sensitivity (q.v.), synthesis dyes, sensitometric curves, inter-image effects, and the possibility of masking (q.v.).

There are two aspects involved, firstly the presence or otherwise of a colour cast in the composite image and secondly the properties of the image when colour casts have been eliminated.

1. *Factors affecting colour casts.* It should be noted that colour casts are produced when the characteristic curves of the three emulsion layers are not coincident and all factors in exposure and printing which contribute to an excess of one image colour compared with another result in colour casts.

(*a*) In general, greys will only be reproduced as grey provided the light used for taking the photograph is that to which the manufacturer has balanced the film. Manufacturers market most colour films in two types: for use in daylight and for use in tungsten artificial light. Compared with daylight film, where the absolute sensitivities of the three layers are substantially equal (owing to the almost equal energy distribution of sunlight through the spectrum) the tungsten balance film has a much faster blue layer and a much slower red layer as the light emitted by a tungsten filament lamp, even when over-run and operating at 3,200°K or 3,400°K, is relatively low in blue radiation and rich in red. If the colour temperature of the light source is not that specified for the film the resulting photograph will have a colour cast. For work of the highest quality this can be corrected by the use of filters over the camera lens. The type of filter which is required can be determined by measuring the light characteristics with a colour temperature meter.

(*b*) The relative slope of the three curves is also important and it is rare to find them parallel throughout their lengths (see Fig. 1). This means that the reproduction of a grey object will have a different colour cast according to its reflection factor — 10 per cent, 50 per cent or 90 per cent; that is according to the optical density. From Fig. 1 it can readily be seen that the neutral colour will vary throughout the density range in five different regions. In zone 1 the greys will be slightly pink, in zone 2 more or less grey, zone 3 blue, zone 4 blue-magenta and zone 5 green. In practice the characteristic curve is divided into three parts,

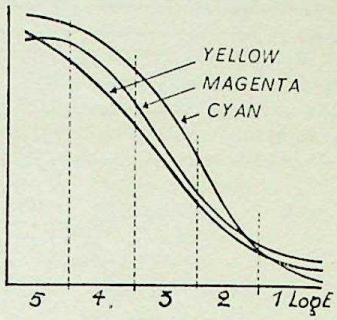


Fig. 1.

the curved toe and shoulder joined by a straight portion; manufacturers generally attempt to make the straight region of each of the three curves coincident. With reversal and positive materials it is also desirable that the toe regions should be well matched as these reproduce the highlights and delicate tints. The aim is, however, rarely achieved and some colour cast in neutrals is usual varying in depth and hue according to density.

(*c*) Finally, errors in exposure, processing or to some extent in viewing conditions may bring in an overall colour cast; this can then be corrected since it is primarily due to a shift in the whole curve affecting all densities equally rather than a lack of parallelism which can be corrected at only one density.

It can be seen from these three factors that the achievement of neutral balance in colour photography is extremely important in the elimination of colour casts both to the manufacturer of sensitive materials and to those who handle them.

2. *Factors influencing the rendering of specific colours.* These factors are those which were mentioned earlier, i.e. layer sensitivity, inter-image effects, etc. It was noted in the section on masking that inter-image effects can have a favourable influence on colour rendering in certain cases. A further effect which can have disastrous results as far as colour rendering is concerned occurs when an image is produced in one layer by chemicals whose effect should be confined to an adjacent layer. This effect would occur, for example, during colour development if the oxidized developing agent produced in one layer were allowed to couple with the colour coupler in an adjacent layer, especially if no image were intended in the adjacent layer (see Fig. 2).

The production of an unwanted colour for any reason in a colour process results in a loss of saturation.

There are various causes of this colour interference. The most common cause is slow coupling between the developing agent oxidized by silver halide and colour coupler dispersed in that layer (see Colour Developers).

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

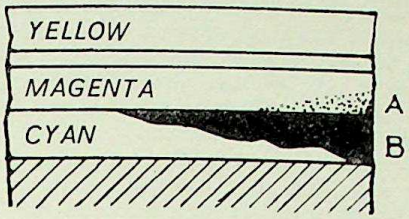


Fig. 2.

A. Contamination image in cyan layer.
B. Development of an image in the cyan layer.

At an interface between two emulsion layers, the risk of oxidized developer passing from the layer in which it was produced to the adjacent layer, and thereby producing an unwanted colour image, is appreciable. The effect can be considerably reduced by physically isolating two coupler containing emulsion layers by means of an inert gelatin layer. In the case of the yellow and magenta layers this object is achieved by the filter layer and most current tripack materials also have a clear gelatin layer separating the magenta and cyan layers. The present aim common to all manufacturers is the improvement in the spectral characteristics of the image dyestuffs themselves. Dyestuffs having unwanted absorptions result in a general greying and degradation of the colour image with a complete lack of bright colours.

The masking technique enables unwanted absorptions to be corrected and improves colour rendering considerably; completely automatic masking processes can now be used with negative-positive systems (Eastmancolor, for example). It should also be noted than at increase in contrast will be accompanied by an increase in colour saturation at the expense of tone rendering. Briefly, image dyestuff characteristics are extremely important and to achieve the most satisfactory colour reproduction in a negative-positive system, some form of masking stage is desirable.

Tone rendering This represents the translation of subject brightness by the print.

A. Subjective aspect. Irrespective of the nature of the subject, or of the medium (painting, printing or photography) tone rendering has a great influence on the fidelity of the representation. It is of prime importance in black-and-white photography. The effect of contrast will be gained from the relative distribution of light and dark areas; the opposition of black-and-white in the microstructure of a print gives the impression of sharpness (this important aspect of contrast will be considered later). Finally the highlight tone rendering is an extremely important factor in image quality.

B. Objective aspect. Photographic tone rendering is linked to the shape of the characteristic curve and to the overall contrast of the reproduction (see reversal process and negative-positive process). As we have seen earlier, tone reproduction will be theoretically correct if the characteristic curve is a straight line and if the overall contrast is unity for either reversal or negative-positive systems.

In practice diffusion effects in camera or projector make a contrast value of 1·5 to 2 more acceptable.

Curves for practical negative, positive and reversal materials are shown in Figs. 3, 4 and 5.

1. *Negative-positive process.* It can be seen that the negative types of emulsion have a relatively long, straight line with the exception of the toe region and that they have considerable exposure latitude, particularly towards over-exposure. A subject can therefore be recorded almost entirely on the straight line portion with only the dense shadows on the curved toe. The positive print material will not have such wide latitude for two reasons: firstly the material is considerably more contrasty and has therefore a shorter log.E range, secondly the print must conform fairly closely to a certain optimum viewing density, particularly if detail is required in both highlights and shadow areas. It is therefore unavoidable in producing prints with satisfactory tone rendering to include the curved toe region of the positive material. The paramount importance of the correct tonal reproduction of highlight areas has already been noted and in this connection the toe shape of the positive material is critical. If the toe is very short,

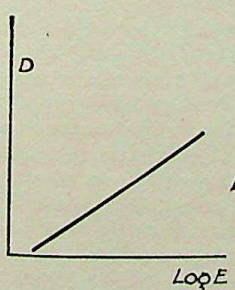


Fig. 3.

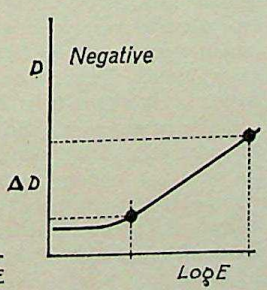


Fig. 4.

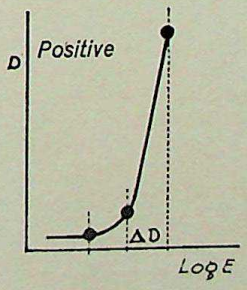


Fig. 5.

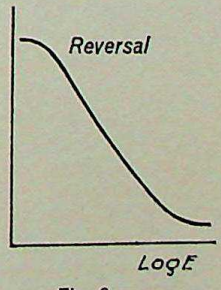


Fig. 6.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

tone reproduction will be excellent even to specular highlights but the printing latitude will be small (Fig. 7).

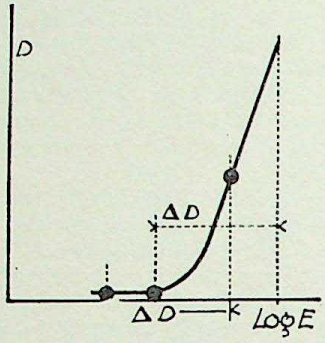


Fig. 7.

At the other extreme, a long flat toe will give a dead and lifeless appearance to the print but exposure latitude will be high; even large exposure errors will not result in reject prints. Manufacturers generally tend to produce a compromise material having reasonable exposure latitude and

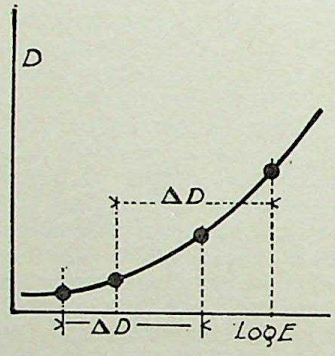


Fig. 8.

adequate tone rendering. It should also be noted that the exposure latitude of papers is effected by the shoulder as well as by the toe region owing to the restricted density perceptible when viewing by reflected light (see Reflection).

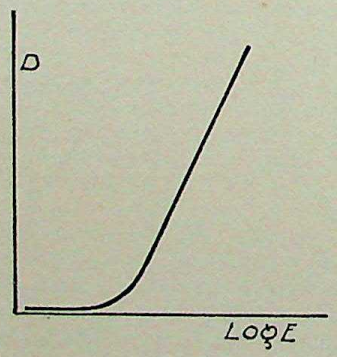


Fig. 9.

2. *Reversal process.* In processes of this type the sensitive material exposed in the camera is used to produce the final positive image. The gamma is usually about 1·5 and the restriction on toe shape leaves little latitude to manufacturers in the choice of characteristics. A rather long toe gives improved exposure latitude but this is never as great as for a negative material (Fig. 10). The total latitude is usually restricted to between 2 and 2·4 log.E and with some processes the shadows quickly clog up and lose detail.

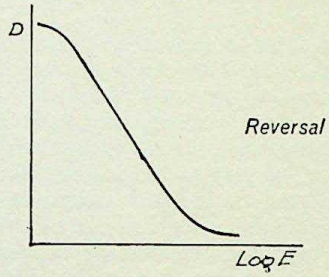


Fig. 10.

Sharpness

Subjective aspect. The sharpness of a reproduction consists of the observer's ability to discern fine detail in it. One important factor is the closeness with which the reproduction is examined.

In the case of paper-based prints examination by the naked eye is all that is normally expected and there is no difficulty in producing an acceptable result. Where projection is involved however, the case is very different as the transparency is enlarged many times and the perceptible sharpness is close to that which the photographic material can record. When dealing with tone separation it was noted that the local contrast over small areas of the image influenced the apparent sharpness and in general a high subjective impression of sharpness accompanies higher contrast.

The relative sharpness of two prints can only be compared if they have the same sensitometric contrast.

Objective aspect. Now that the importance of contrast is understood, the examination of the factors influencing sharpness in the sensitive layers can be made. Acutance is one of the more recent concepts. According to Jones and Higgins the subjective impression of sharpness is related to the contrast gradient between light and dark areas in photographic material. The acutance can be defined as a function of this contrast gradient; by referring to the gradient of known materials the behaviour of a new one can be forecast. The point is illustrated in Figs. 12 and 13 where one material has excellent acutance and the other poor acutance.

In practice the sharpness of the photographic

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

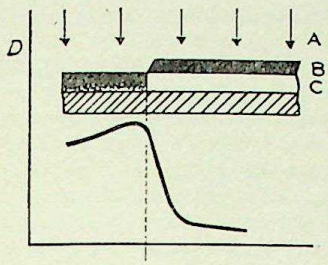


Fig. 11.—A. Light.
B. Sharp edged screen
C. Sensitive layer.

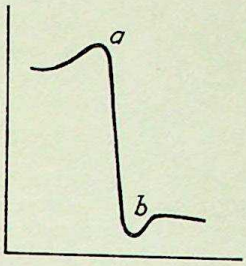


Fig. 12. — Good acutance is favoured by conditions a and b.

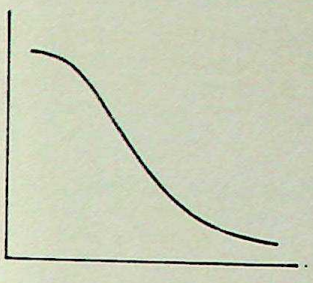


Fig. 13. — Low acutance emulsion.

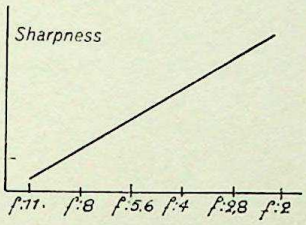


Fig. 14.
At small apertures diffraction effects cause a loss in sharpness.

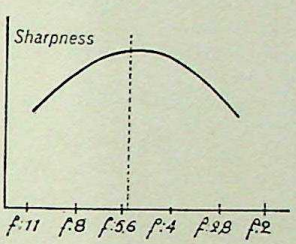


Fig.15.

image is influenced by the image given by the camera lens as well as by the acutance of the sensitive layer. As far as lenses are concerned, readers are referred to the appropriate section; here only the photographic aspects will be considered.

Pinoir has established that although the resolving power of a lens may increase with its geometrical aperture, the practical result when using a lens in conjunction with a photographic material usually shows an optimum sharpness at about $f/5{\cdot}6$ with a more or less gradual fall off at greater and smaller apertures (Fig. 14). Put simply, this is because at smaller apertures diffraction effects result in a loss in sharpness whilst at larger apertures the marginal rays of the lens spoil the definition. Knowing this, it is interesting to examine microscopically the image of a knife edge or other well defined object. The photographic image has a discontinuous structure as it is made up of individual silver grains. It also exhibits signs of light spreading due to the turbidity of the emulsion layer. As photographic emulsion is not a transparent medium, light entering it is subject to reflection, refraction and diffraction. This optical distortion of the image in the sensitive layer results in a loss of sharpness. The thicker the sensitive layer the greater is this loss. Ideally to record a sharp image the sensitive layer should not be more than 10 to 12μ thick. In the case of multi-layer colour films this ideal cannot be realized and the total emulsion thickness varies

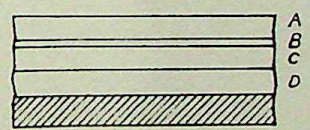


Fig. 17.
A. Yellow layer, blue sensitive.
B. Yellow filter.
C. Magenta layer, green sensitive.
D. Cyan layer, red sensitive.

according to type from 22 to 30μ. This is obviously detrimental to sharpness and the loss is accentuated by the necessity to have a layer structure: yellow emulsion, yellor filter layer, magenta emulsion, cyan emulsion (see Photographic

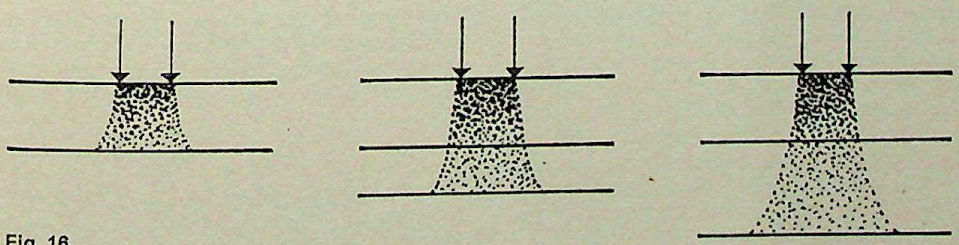
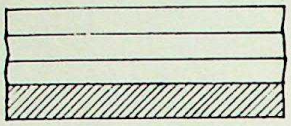


Fig. 16.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Fig. 18.



Reproduction of Colour). Inevitably the cyan image is therefore less sharp than the magenta one and both are inferior to the yellow. Infortunately it is the cyan and magenta images which contribute most to the impression of sharpness. The sharpness of the yellow image on the other hand is of no great importance. In theory, therefore, the layer order forced upon film manufacturers is the worst possible one and attempts to ameliorate this situation are being made using thinner and thinner emulsion layers.

In positive emulsions where high sensitivity is not at a premium chlorobromide emulsion are now being used. These have an intrinsic sensitivity in the ultra-violet and violet but are susceptible to selective colour sensitization and can therefore be coated in any desired order. Eastmancolor positive, and more recently Gevacolor, used a layer order capable of giving greatly increased sharpness. Sharpness losses due to lateral spreading of light are greatly reduced by introducing a fugitive absorbing dyestuff into the sensitive layer although this at the same time reduces sensitivity. Eastmancolor positive film has an overall purplish-magenta appearance due to the incorporation of such a dye.

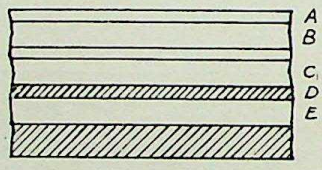


Fig. 19.
A. Supercoat.
B. Magenta dye, green sensitive.
C. Red sensitive.
D. Blue anti-halo layer.
E. Blue sensitive.

Graininess Unlike colour rendering and tone separation, this important aspect of a colour photograph is not associated with the subject itself but is essentially related to the sensitive materials.

Subjective aspect. Graininess is the name given to the discontinuity of the image structure. When grainy pictures are seen successively as in motion picture projection a disturbing moving pattern is seen. As with sharpness, the impression of grain depends on the degree of magnification. All the remarks concerning sharpness apply to graininess also. One of the main limitations of wide-screen projection in cinemas is the graininess of the greatly enlarged image.

Objective aspect. Graininess in colour materials is bound up with two phenomena.

Firstly the graininess of the emulsion itself. This is obvious when it is remembered that in black-and-white work slow fine grain emulsions such as Kodak's Panatomic-X have a much finer grain structure than have the more rapid films such as Plus-X or Tri-X. The actual grain structure is not the main visible feature — rather the aggregation of individual silver grains during development. The discontinuity of the grain structure of an unprocessed emulsion is visible only with a microscope but the aggregation during development is such that the grain structure can be seen with a simple magnifier.

Secondly the optical intensification caused by the colour development process must be studied.

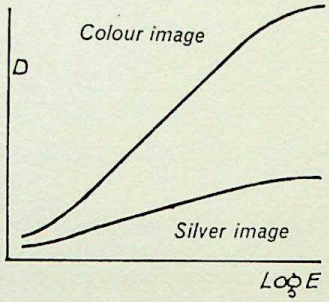


Fig. 20.

Fig. 20 illustrates the increase in density which can be expected when a dye image is produced alongside a silver image. The silver curve corresponds to white light measurements and the dyestuff curve represents measurements made with complementary light. The usual ratio of dye density to corresponding silver density is between 3 and 4 to 1. The dimensions of the individual patches of dye therefore tend to be larger than the silver grain from which they are produced (Fig. 21). In practice this results in grain increase in a colour emulsion compared with a similar emulsion used for black-and-white work.

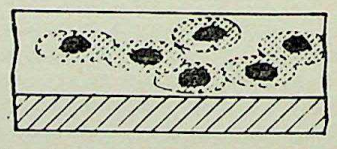


Fig. 21.

A further factor influencing graininess is the dispersion of the dye; if the dye diffuses to some extent around the developed silver halide grain, the impression of graininess will be reduced.

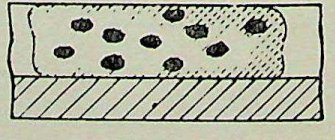


Fig. 22.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

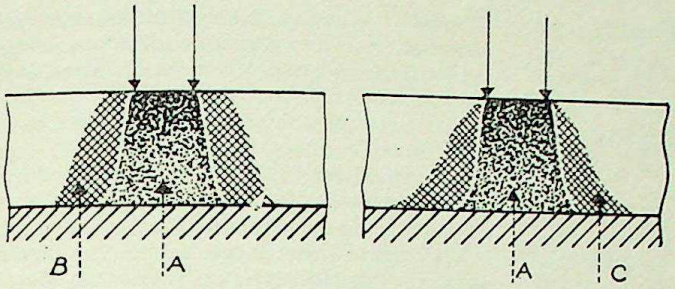


Fig. 23.
A. Silver images.
B. Dye image, reactive coupler.
C. Colour image with less active coupler (note the spread).

This diffusion is based upon the reaction rate between the oxidized developing agent and the colour coupler present in the emulsion layer. For example, if this rate is low, the oxidized developer will spread from the site of formation before coupling and each individual 'grain' will tend to blend with its neighbours thereby reducing the impression of graininess. This diffusion not only reduces graininess but also sharpness. One aspect of the sharpness of a colour image is in fact connected with the lateral spreading of the dye (Fig. 23). This lateral spreading has the same effect on definition as turbidity.

In short, by suitable choice of couplers it is possible to increase the apparent sharpness but only at the expense of increasing the graininess. The relationship between these two phenomena should be noted; definition and graininess are frequently misinterpreted.

Conclusion Four main features — colour rendering, tone separation, sharpness and graininess, therefore, contribute to the general impression given by a colour picture and modern processes vary in the importance in which these factors are placed. In motion picture work, definition and graininess are the present limiting factors and must be improved before any increase in screen size can be made.

COLOUR TEMPERATURE METERS

Colour emulsions are normally balanced for one of the customary light sources.

- 5,600°K for emulsions intended for use in daylight.
- 3,800°K for emulsions intended for use with clear expendable flash bulbs.
- 3,400°K for emulsions used with photoflood lamps or yellow flashbulbs.
- 3,200°K for emulsions intended for use with studio lamps.
- 2,900°K for existing tungsten illumination, e.g theatre lighting.

In most cases it is sufficient to know the type of lighting and to select a suitably balanced emulsion. The actual colour of the lighting need not be that given in the table; daylight is affected by weather and atmospheric conditions, and by the time of day, and artificial lighting can be influenced by the age and condition of the lamp, the voltage and the colour of reflections or lenses. Any irregularities can be corrected with filters. The actual colour of the light can be measured with a colour temperature meter, which, in its simplest form, contains a photo-cell similar to that used in an exposure meter, a galvanometer, and red and blue filters. A reading is made through each filter which represent the extremes of the spectrum and from the ratio of the two readings the colour temperature in °K can be calculated. One method of doing this in practice is to first take a reading through the red filter and by means of a diaphragm adjust the amount of light reaching the filter so that a predetermined position is indicated. The blue filter then replaces the red filter and the deflection of the needle indicates the colour temperature directly on the graduated scale.

Other commercial meters use two cells fitted respectively with red and blue filters; these are connected to the same galvonometer and by taking only one reading the colour temperature is indicated directly. Colour temperature meters are suitable only for the measurement of light having a substantially continuous spectrum. They are not suitable for measurements of lamps emitting monochromatic light or light with a discontinuous spectrum such as that emitted by most fluorescent lamps.

COLOUR VISION

Colour perception and reproduction are complicated by involving three different processes: physical, physiological and psychological. Only the last of these three operates when a colour photograph is compared with the original subject yet the other two are essential intermediates.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

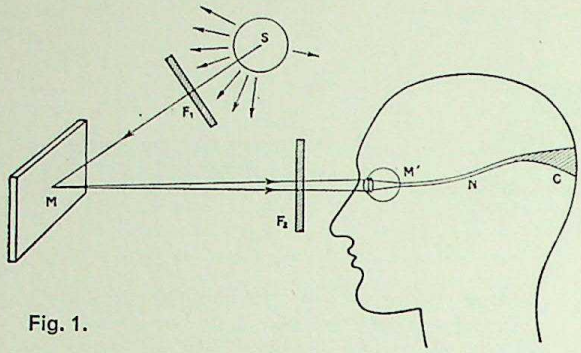


Fig. 1.

Physical process Take the case of an observer viewing a point M on a diffusion surface (Fig. 1). The surface is illuminated by light source S and the light may pass through coloured screens or filters F_1, F_2, the first being in the form of a coloured glass bulb and the second, spectacles worn by the observer. The cornea and crystalline lens of the observer's eye behave in a similar way to a camera lens and project an image M_1 of point M on to the retina. The physical step comprises the total path SMM_1.

The physical factors which will affect the colour perception on this path are described elsewhere, see Colour, Light and Photometry. The first point to consider is the nature of the radiations emitted by source S and in particular the spectral distribution of the light over the relatively narrow visible region of 0·4 to 0·7μ. Secondly the absorption by filter F_1, then the absorption and reflection characteristics of suface S, and finally the absorption by filter F_2 and by the eye itself. The absorption along the path SMM_1 by the atmosphere and water vapour should also be considered to complete the picture. The absorption due to the eye structure is frequently ignored as it is reasonably constant for one observer, varying only slowly with age. As the age of the observer increases the cornea and crystalline lens tend to become yellowish thereby reducing the light of shorter wavelengths; the longer wavelength light is hardly affected.

Physiological stage When light reaches point M_1 on the retina of the eye, part of it is absorbed, and this forms the basis of vision. The mechanism of vision in bright light is still hardly understood, although at night or in conditions of poor lighting where the eye has had about 15 min. to adjust itself to the low light level, the mechanism is better known. The low level receptors are known as rods and contain a protein substance which is an aldehyde of vitamin A known as 'visual purple'. This visual purple is decomposed by light and re-forms in the dark; the decomposition process is believed to produce an electrical impulse which excites the nerve ending. The rods play no part in colour vision which is virtually absent at very low light levels.

Under daylight or bright artificial light conditions the rods cease to be active and the perception of colour and brightness is carried out by the other retinal cells, the cones. It is likely that the cones contain one or more photosensitive substances akin to visual purple but present in much smaller quantities — so small in fact that isolation of the substances is extremely difficult.

It is not, however, visual purple itself, as the sensitivity curve has its peak in the longer wavelengths. The Purkinje phenomenon of darker reds and lighter blues with decreasing light level is explained by the presence of two different photosensitive substances.

Electrical potential differences can be detected on animal eyes and even on human eyes when the eye is subjected to variation in lighting but these electro-retinograms have so far given no clue to the mechanism of colour vision.

The trichromatic theory A law of great theoretical and practical importance was expressed a century ago in the trichromatic theory which states that only three colours are necessary to express any given colour. It constitutes a great improvement over the physical method of expressing the colour of light of defining the energy at all the wavelengths present. The trichromatic theory forms the basis of most photographic colour processes. It is impossible for the eye to analyse light into constituent wavelengths. It has been shown experimentally that two coloured lights can be visually indistinguishable yet may have totally different spectral composition. If the eye were able to analyse light into its elemental wavelengths then colour photography would only be possible by means of methods such as the Lippmann and Lanchester processes (see under Historical) which attempt to reconstitute the physical nature of the light received from the photographed object.

Although the trichromatic theory has been completely demonstrated, the mechanism is still unexplained. The Young-Helmholtz theory requires the presence on the retina of three receptors or cones sensitive respectively to the long, medium and short wavelengths. No practical support for this theory has been forthcoming as examination of the cones indicates that they are all similar except for the influence of their situation on the retina. It should be restated that although the trichrome theory cannot be explained its existence has been amply demonstrated.

Primaries and fundamentals The physiological simplification outlined by the trichromatic

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

theory has consequences of great practical importance, namely the possibility of a trichromatic synthesis of all colours. Only the additive processes will be discussed here as the subtractive ones are not as closely linked to the trichromatic theory (see Colour).

The principle of the additive system is as follows: there are three different colours called primaries. By superimposing them in different proportions, various colours can be produced — in particular white. The exact choice of the three primaries is arbitrary but the richest and deepest colours are obtained from red, green and blue monochromatic radiations. In practice almost all colours can be reproduced in this way as far as visual perception is concerned — not their absolute physical composition. The exceptions are certain blue-greens and pure violets which are fortunately not commonplace. In theory the best primaries are monochromatic radiations but in practice coloured filters are used over a white light source and the colour of each primary is defined by the spectral transmission of the appropriate filter.

It is obvious that the three negatives or the mosaic obtained on a single negative which are used for additive synthesis, must follow some laws for the successful reproduction of colour; these laws are termed the colour mixture laws but should not be confused with the colour mixing of pigments on a palette which is affected by entirely different principles. The colour mixture laws vary from one individual to another but if colour blind persons or those with abnormal colour perception are eliminated, a 'reference observer' can be adopted with standard characteristics. In the trichrome theory the standard observer's characteristics would correspond to the sensitivity curves of the supposed receptors. Fig. 2 illustrates the general shape of these curves, which show for each wavelength the response of the three receptors. It can be seen that the receptor B, sensitive to blue light, has a peak response at about 450 mμ, that for the green is about 550 mμ, whilst the red receptor has a peak at about 500 mμ. It can be seen that a large proportion of wavelengths excite all three receptors; radiations with wavelengths above 560 mμ no longer excite the blue receptor. This explains one great feature of the trichromatic theory in that yellows, even of the highest purity, can be reproduced by mixtures of red and green light.

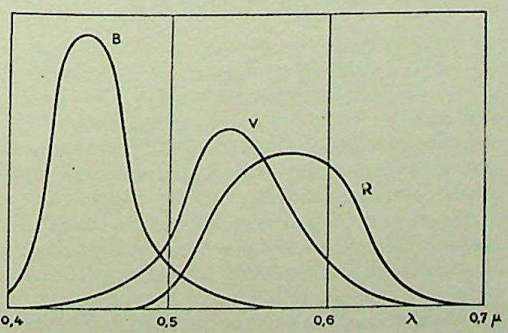


Fig. 2.

Adaptation As we have just seen, the main features of colour vision are controlled by the structure of the retina and in particular to trichromatic vision. Retinal functions are also closely linked to adaptation phenomenon. For example, continuous exposure to coloured light results in a loss of retinal sensitivity to that particular colour; thus incandescent light when first seen by an eye accustomed to daylight will appear yellow but after a time the mechanism of adaptation will lead to its acceptance as white. With the eye adapted in this way a return to daylight conditions will have a pronounced blue effect. The main mechanism is a balance of the sensitivity of the retinal receptors, white light causes equal excitation of red, green and blue receptors, yellowing light on the other hand will excite the red and green receptors to a greater extent than the blue one. The eye will, under these conditions, automatically suppress the sensitivity of the red and green receptors until the response is practically equal to that from the blue receptor and the light will then appear white. With the receptor's sensitivity so adjusted, a return to true white light conditions will result in greater excitation of the now more sensitive blue receptor and the white light will appear blue.

This explains why in colour photography emulsions of different colour balance (or alternatively colour correction filters) must be used when photographing with different light sources, for colour films have no automatic adaptation mechanism similar to that of the eye, and the yellowish impression of tungsten light by an eye adapted to daylight is comparable with the yellow result produced by tungsten exposure of a daylight balance film.

Continuation of the physiological step To complete the physiological system, the optic nerve N and the centre C in the brain must also be considered (Fig. 1). The optic nerve can be compared with a telegraph system capable of carrying 800,000 different signals, each corresponding to one sensitive element of the retina. Electrical signals are, in fact, transmitted as groups of dots varying between 1 and 100 per sec. according to the excitation. The frequency of the dot pattern increases with the log of the luminosity of the light reaching the particular sensitive element. This is probably the origin of the Weber-Fechner Law which states that the minimum perceptible variation of intensity (that is the smallest dot frequency which can be distinguished)

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

is in fact proportional to the intensity itself.

As far as colour vision is concerned it is assumed that some fibres of the optic nerve are adapted to carry signals from receptor R, others from receptor G, and a third group from receptor B. There is no direct proof of this but if it is true then the R transmitting fibres have a greater diameter than the G ones which in turn are bigger than the B ones. This must be so as the delay between excitation and perception of the red light is less than that for green light, which in turn is less than that for blue light. When the signals reach the centre C situated in the rear part of the brain, electrical impulses still remain which, even in the case of man, can be detected through the skull but unfortunately these provide no information on the mechanism of colour vision.

Psychological step When the signals reach the brain centre C they disperse in the surrounding brain tissue in a way which has been known for some time. Here are found the three characteristics of the phychological stage; they are value (light or dark), hue (red, orange, yellow, etc) and saturation (degree of dilution with white). In short the value is the interpretation of the diffuse reflection factor, in other words the luminosity. The hue corresponds to the colorimetric conception of dominant wavelength or the wavelength of monochromatic light. Saturation corresponds to purity of hue. It is in fact not the object of visual perception to analyse light like a colorimeter but merely to facilitate recognition and enable work to be carried out. The result of this is that colour cannot be isolated as an attribute independent of the object's surface since the grain, texture or polish of the surface also affect the perceived value. This explains degraded colours like browns, olive-greens, etc. Photographic reproduction must suggest these factors, and this is assisted by careful location of light sources. For example to create the effect of glaze on porcelain small reflections must be present on the surface of the object but the colour must not be completely obliterated by these reflections which must merely suggest a high surface gloss.

An important characteristic of the psychological stage is the maintenance of what has been termed the constance — the constancy of shape despite changes in perspective or the constancy of perceived colour despite changes in lighting. Colour memory is a different and more complex attribute; it is also possessed by animals. Hens have been trained to select grain of a given colour from variously tinted samples and they never make a mistake even when the colour of the light in the hen house is changed. They can, like human beings, apparently adapt themselves to the changed lighting conditions and still register the more permanent colour of the grains.

The photographic reproduction presents problems in this field as the constancies are less easily adapted in a colour photograph than when viewing an actual scene. For example, shortening the viewing distance may grossly distort the perspective and this can only be cured by adopting a more distant viewpoint as in Rembrandt's famous 'anatomy lesson'. Similarly the brightness of the surroundings of a colour reproduction differ from the surroundings of the original and this gives the reproduction a false aspect, brightening it if the surroundings of the reproduction are dull. A good colour photographic reproduction will not necessarily be the one in which objects are colorimetrically exactly reproduced but may have deliberate systematic errors which assist the psychological interpretation of the reproduction under the normally expected viewing conditions.

Colour contrasts The word contrast has many different applications but when applied to colours usually indicates that if two radically different colours are present in an observer's field of view, their mutual effect is to brighten each other. There are a number of physiological and psychological factors involved: for example the continual movement of the eye from one area to another and the process of adaptation results in an alternating change in sensitivity of the retina as each colour is observed and the colour successively viewed then appears brighter. There are also a number of psychological effects which the photographer must take into consideration.

COLOURED COUPLERS

Introduction The practical problems of registration of masks (q.v.) with their separation negatives or with the original transparencies has never been a great obstacle when applied to photomechanical systems or to three-colour assembly processes such as Dye Transfer or Carbro.

The use of masks in commercial motion picture processes has not been widely used despite the improvement which would result. This was due to the difficulty of accurate registration in high-speed printing operation. The introduction of the Eastmancolor process enabled the correction for unwanted dye absorptions to be carried out automatically without the use of any auxiliary mask on a separate film.

The coloured coupler system used in Eastmancolor is based upon the methods already utilized in

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

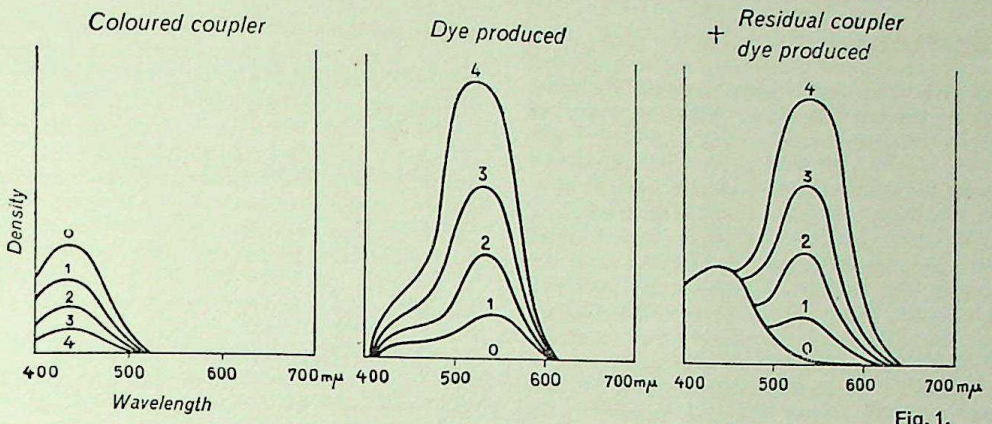


Fig. 1.

other Kodak negative-positive processes — Ektacolor and Kodacolor — for professional and amateur still photography respectively. The basic work was carried out by Hanson and Vittum. A somewhat similar process was devised by Ganguin and used in the ICI colour process.

Definition of coloured couplers A coloured coupler is a compound capable of reacting during colour development to give a cyan, magenta, or yellow dye, and whose original colour corresponds exactly with the unwanted absorption of the image dye produced. For example, a coupler used to produce the magenta image (which has an unwanted absorption in the blue) will be coloured yellow — the complementary colour to blue.

Mechanism This will be illustrated with reference to the following example:

Assume we have a magenta-coloured photographic image obtained by the use of yellow coupler as already described. The spectral characteristics of the coupler and of the resulting dye at various concentrations are shown in Fig. 1.

The digits 0, 1, 2, 3 show respectively the absorptions of the dye formed and of the residual coupler for these different concentrations after colour development. The curves 0 correspond to an area which has had no exposure; no colour development has therefore taken place and the coupler remains intact.

At the other extreme, 4 corresponds to an area of maximum magenta density where all of the coupler has been converted to magenta dye.

Curves 1, 2 and 3 correspond to intermediate exposures and therefore to intermediate concentrations of image dye and residual coupler.

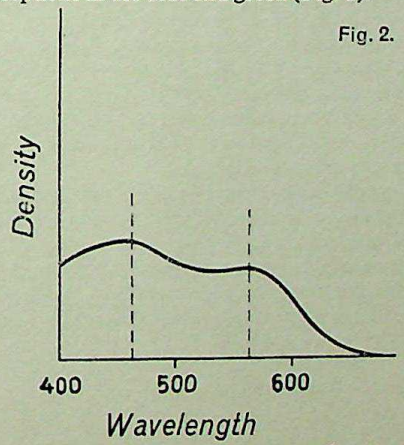
By suitable choice of the hue and intensity of colour in the coupler, the sum of the unwanted blue absorption of the magenta dye and the blue absorption of the residual coupler remains constant through the entire concentration range.

Under these conditions the magenta image is therefore automatically corrected for its unwanted blue absorption by making it uniform over the whole image area.

This method differs fundamentally from the classical conception of masking correction in which the amount of yellow dye produced in the print is reduced at any given point in proportion to the amount of magenta dye present. In the final result, however, the effect is the same when the coloured coupler image is only used in an intermediate stage, for example in the negative of a negative-positive process. The Kodak negative processes utilizing this technique possess a background density uniformly distributed over the entire image, giving it an appearance of being useless as it is.

On the same reasoning it can be seen that an orange-coloured coupler can be (and is) used for the correction of a cyan image with unwanted absorptions in the blue and green (Fig. 2).

Fig. 2.



Orange-coloured cyan coupler.

The use of magenta and cyan images resulting from the use of yellow- and orange-coloured couplers give Eastmancolor and Kodacolor negatives a distinctive appearance in which the unexposed areas have a strong orange-yellow colour.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

COUPLERS

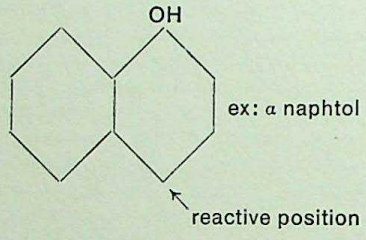
Definition A coupler is a reagent which participates in the dye formation during the process of colour development. The dye is deposited together with the metallic silver of the developed image; the latter is removed to leave a substantially pure dye image. (See Colour Developers.)

The couplers may be present in the developing solutions (Ilfachrome, Kodachrome) or in the three emulsion layers (Agfacolor, Anscochrome, Ektachrome, Ferraniacolor, Gevacolor, etc.).

CHEMICAL CONSTITUTION

A large number of compounds can behave as couplers during colour development. All fall into one of two groups:

1. Phenol or naphthol derivatives where the reactive group is in the para-position to the hydroxyl



2. Compounds containing an active methylene group at which the coupling reaction takes place

$$R_1 - CH_1 - R_2$$

Couplers in the first group give blue or cyan dyes whilst those of the second yield yellow or magenta dyes depending on the groups R_1 and R_2.

As with colour developing agents the nature of the substances and the exact chemical constitution determine the solubility, the stability, the rate of diffusion in an emulsion layer, the activity and the colour — both of the coupler itself and of the dye which results from coupling.

Generally there are two or three functions in the coupler molecule which affect its properties more or less independently.

First is the factor which plays the main rôle in determining the colour — naphthols giving blue or cyan dyes for example. The substituents mainly affect solubility and diffusion, and below are given the important characteristics of couplers used in commercial processes.

A. KODACHROME COUPLERS

(see Kodachrome)

The couplers must be readily soluble in the developing solutions and they must also diffuse freely into the emulsion together with the colour developer. Briefly these couplers must have the coupling function and substituents to give the dye the correct colour, a hydrophilic group to give solubility in the developer solution and at the same time the molecular weight must be reasonably low to give good diffusion properties.

Examples:

2:4-dichloro-1-naphthol	for cyan
naphthoylacetonitrile	for magenta
acetoacetanilide	for yellow

B. COUPLERS INCORPORATED IN THE EMULSION

In this case it is essential that the coupler should not diffuse from one layer to an adjoining one after the layer is coated.

1. Agfacolor, Anscochrome, Ferraniacolor and Gevacolor processes These processes all use couplers which are sometimes referred to as the Agfa type, an example of which is given below:

Example:

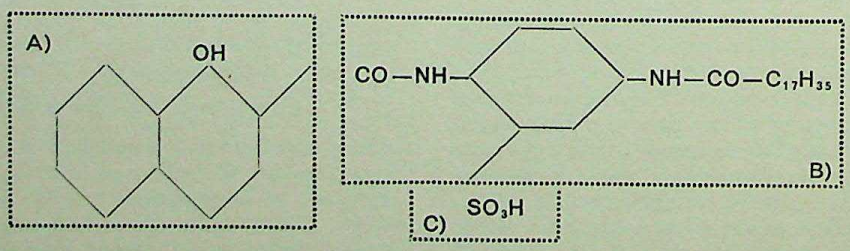
1-stearoylamino-4-(1′-hydroxy-2′-naphthoyl-amino)-benzene-3-sulphonic acid.

The part A of this molecule is the coupler function which determines the colour; being a naphthol the colour in this case is cyan.

The part B is a long chain constituted principally of carbon atoms. Its object is to increase the size of the molecule and prevent it from diffusing out of the emulsion layer — in other words to 'anchor' the molecule.

The part C is the group which gives the coupler enough solubility in water (containing caustic soda) to enable a solution to be prepared and mixed with the fluid emulsion before coating.

2. Kodak Process The couplers used in the Kodacolor and Eastmancolor processes basically



CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

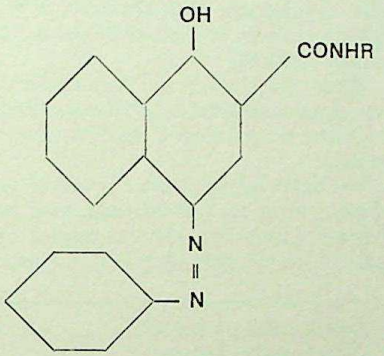
possess the same characteristics as the preceding ones with the following exceptions:

The anchoring chain is not of the same chemical type as that of the Agfa couplers (this is largely a matter of patents).

The hydrophilic solubilizing group is not present. The result of this is that the compounds are soluble only in organic solvents such as oils; solutions are then mechanically dispersed in the aqueous emulsion as droplets of a size in the order of a micron.

Note. It should be noted that the Eastman and Kodacolor processes utilize coloured couplers. These are similar to normal couplers except that the coupling function has an azo chromophore substituent. This group is split off during coupling when the normally produced azamethine dye is formed.

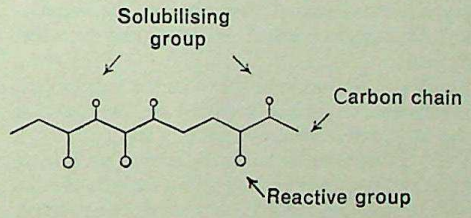
Example of coloured coupler

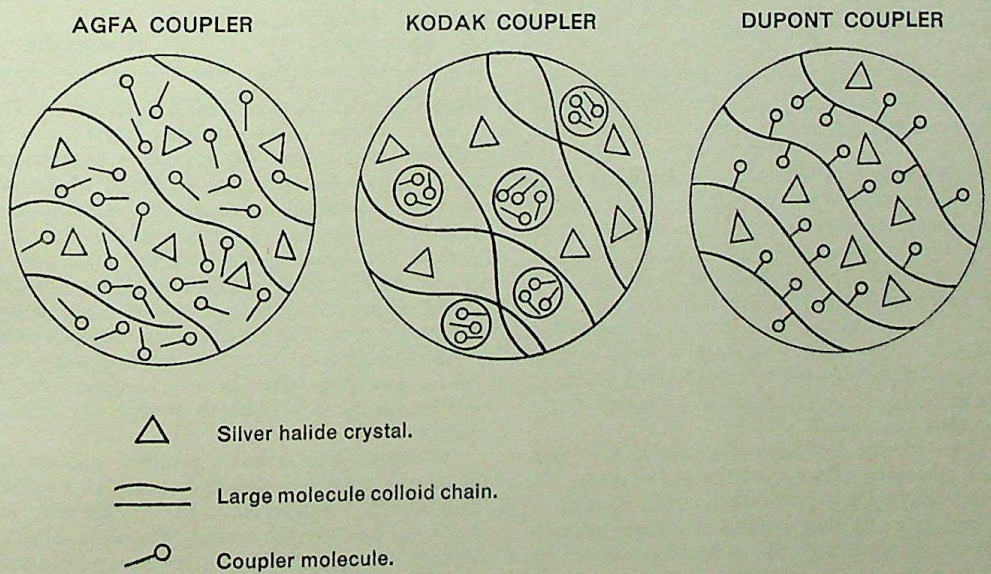


It should be remembered that the coloured coupler system will only work if the chromophore group is automatically eliminated at the moment of coupling. It has been found that this only occurs if the chromophore group (of the diazo type) is present in the molecule in the position at which coupling with the oxidized colour developer occurs.

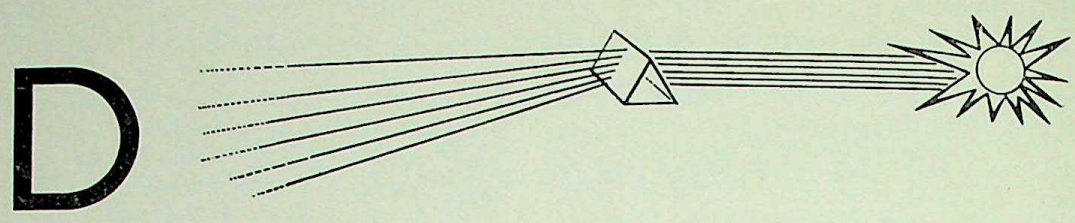
3. **Du Pont polymer couplers** The double problem of manufacturing couplers which will not diffuse from the appropriate emulsion, and of incorporating these couplers into the sensitive layer has been elegantly solved by the use of polymer couplers (Du Pont). These essentially comprise a long carbon chain on to which yellow, magenta and cyan coupling functions have been grafted, together with groups which confer water solubility. If this is related to the preceding remarks it can be seen that these couplers contain a multiple Agfa-type coupler structure with the long carbon chain serving as the anchoring unit. Furthermore, the physical properties of these polymers are such that they can replace gelatin as the protective colloid binder for the silver halide. This method was for a time used in a cine positive material manufactured by Du Pont.

The schematic diagram shows the disposition of coupler, silver halide and binder (gelatin or polymer) in the three cases of Agfa, Kodak and Du Pont systems.





CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



DAYLIGHT

As our surroundings are normally viewed in daylight, artificial illuminants are only satisfactory in so far as they enable the daylight aspect to be approximated.

The form of an object is given by the relationship of highlights and shadows; this distribution of shadow and highlight enables a completely new and unknown object to be distinguished among familiar surroundings.

Colour, which is normally perceived after form, can often lead to incorrect identification.

Unskilled observers who have had no training in colour appreciation for either artistic or professional purposes, usually judge colour very summarily — colours of objects being considered quite independently of other factors. A colour is reproduced accurately when it gives the impression that it is being viewed under midday sunshine conditions.

Some account must be taken of the psychological factors affecting the situation — the direction of the light, reflections, the lighting level, etc.

Factors which must be considered in producing an acceptable colour reproduction include atmospheric conditions, the time of year, the orientation of the sun relative to the subject and the lack of perfection in the emulsion itself.

Emulsions Most reversal colour films are available in at least two types: for daylight and for special tungsten light (and possibly for clear flash also).

In England and America the tendency is to balance daylight films to about 5,600°K, which corresponds to mean noon sunlight at Washington, D.C.; this standard is applicable to most temperate latitudes. Photographs taken with daylight film will therefore be balanced at this time of day.

Before the sun has reached a certain elevation and after it has again fallen below this elevation when setting, the colour temperature changes; this change may not be noticeable to the eye but is recorded by colour film.

If we admire the effect of a sunrise or sunset, the unexpected colour variations cause no surprise as our colour vision is slowly adapted to the gradual change in the lighting conditions and no comparison can therefore be made with colours which we consider 'natural'; but when a photograph is viewed under normal daylight conditions or by projection it is difficult to believe what we have actually seen.

With a little experience the eye can be adapted to visualize again the scene as it appeared when the exposure was made but it is desirable to be able to prejudge this apparent lack of colour fidelity in order to reproduce the aesthetic effect which is desired.

Time of day is not the only consideration; the sky, clouds and latitude all have some effect.

Colour temperature is dealt with in the section on light.

The table below shows the colour temperature of daylight under various conditions expressed in degrees Kelvin and also the degree of tolerance which is permissible using daylight emulsions.

Average midday sunlight	5,400
Direct midday summer sunlight	5,500
Midday sunlight and blue sky	5,900
Lightly overcast sky	6,800
Heavily overcast sky	7,500 to 8,400
Very blue sky, pure atmosphere	12,000 and more

INFLUENCE OF THE SUN'S ELEVATION

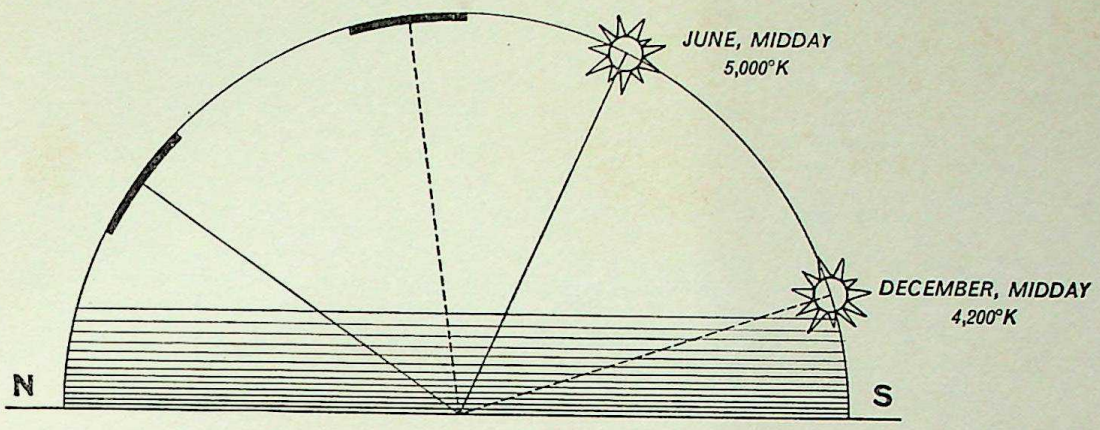
1. On colour temperature Irrespective of other climatic conditions, the colour temperature of sunlight varies with the elevation of the sun above the horizon. Under very clear conditions, at sunrise and sunset, the sunlight travels through a greater atmospheric thickness and is richer in longer wavelengths — red and yellow — whilst the blue content is diminished. Sunsets are characteristic for orange and green tones. At these times of day sunlight is weaker as well as warmer in colour and this light has been depleted by the greater thickness of atmosphere through which it passes.

At sunrise and sunset the colour temperature of the sun is low, varying from 2,000°K to 4,200°K in December at an elevation of 18°. When the sun is at the horizon the colour temperature of the light is extremely low but once the sun has passed

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



below the horizon the colour temperature of the light, provided only by the diffused light from the sky, rises quickly to about 8,000°K.

It is often noted how intensely blue the sky appears at such times despite the darkening which takes place.

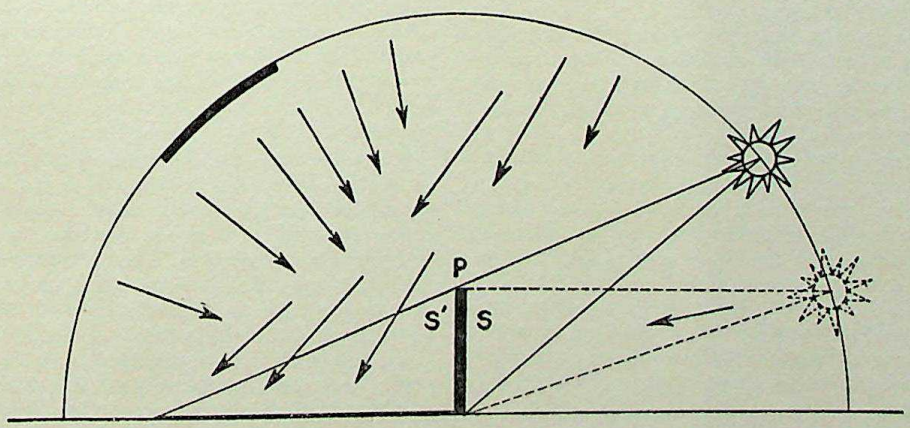
The values which have just been given are those for sunlight itself, no account being taken for the effects of diffused sky light or for clouds. In extremely clear weather the diffused light from the general direction of the sun is the strongest and has a colour temperature approximately the same as sunlight; the diffused light is at its weakest and its colour temperature at its highest around a point 80° from the sun's direction in a vertical plane and about 20° each side of this plane. The colour temperature may reach 20,000° in this region.

2. On the distribution of highlights and shadows All subjects lit by sunlight receive the light directly from the sun itself and also some light diffused by the sky and clouds.

If a vertical plane P is considered whose surface S faces the sun, it will receive light direct from the sun together with diffused light from the sky which may subtend an angle of 90° if there is no obstacle in the way.

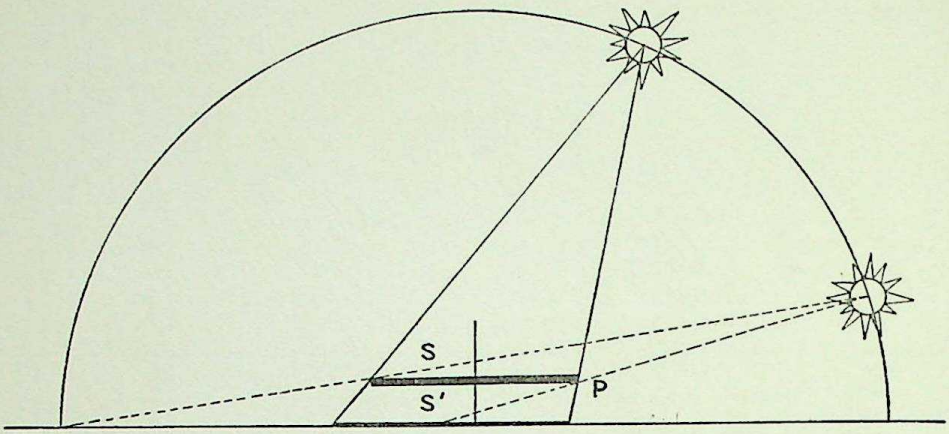
The reverse surface S′, on the other hand, receives only the diffused light from the dullest part of the sky. This, the shadow area, has a high colour temperature and therefore reflects a high proportion of blue light; its brightness is about one-quarter and may be as low as one-eighth that of the directly lit surface S.

The shadow cast by the plane P receives light from a wider area of sky; the length of the shadow increases as the sun approaches the horizon and the end of the shadow is brighter and less blue



◀ Flash portrait by George Blitz using a Retina Reflex camera and Kodachrome film.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



than the beginning close to the plane P. Shadows do not appear blue only because of their contrast with warmer colours; they are actually blue.

The illumination of the vertical surface S varies according to the elevation of the sun and is at a maximum when the sun is at an angle between 18° and 40° to the horizon; above 40° the illumination drops rapidly and the shadows are shortened and intensified.

If the plane P is horizontal, the direct light received by it is almost nil at sunrise, gradually increasing as the sun ascends, and is at a maximum at the sun's zenith. The plane receives the whole of the diffused light from the sky which is at a higher colour temperature than in the previous example.

A horizontal surface always reflects more blue light than a vertical one. The surface S1 will receive no sky light, only light reflected from the ground. Its shadow will therefore be much darker than that of the plane P, deepening as the plane becomes nearer the ground and the diffusion from the sky becomes stronger as the sun approaches the horizon. This part only receives a certain amount of blue light.

All sloping surfaces which face the sun are subject to both forms of sunlight. If the plane is perpendicular to the line of the sunlight it reflects light of the colour temperature of the sun and the adjacent sky area.

In the above, to express the 'quality' of the light more exactly the question of 'quantity' emitted in the various examples has not been dealt with. This extremely important factor can be readily measured by the photographer using a photo-electric exposure meter.

Knowledge of the colour of the centre of interest of the subject enables a first approximation to be readily made and gives some guidance on corrections which may be necessary in working out the exposure.

INFLUENCE OF ATMOSPHERIC CONDITIONS

The elevation of the sun is not the only factor affecting colour temperature or the relationship of highlights and shadows. Atmospheric conditions can produce a number of effects which are difficult to control.

So far shadow and highlight conditions have been dealt with when the atmosphere is very clear and contrast therefore at its maximum.

Under these conditions the light falling on a surface perpendicular to the sun at midday varies little throughout the year, and is about 800–1,000 ft./candles.

In hazy conditions when distances are diffused the light reaching a similar plane may only be one-fifth of that reaching it in clear weather. The presence of haze decreases the direct light and also decreases the difference between highlight and shadow areas until shadows finally disappear when the sun is completely masked.

At nightfall low-lying mist may develop which can obscure the sun; the diffused light is a mixture of sky light and sunlight and may have the same colour temperature as that of the higher atmospheric layers and is very rich in warm colours.

With an overcast sky the light level may be quite high (300 to 400 ft./candles) but may fall as low as 100 ft./candles.

When the sky is cloudy but the sun is not obscured, the clouds reflect light which is added to the diffused sky light but is much stronger; the colour temperature is much lower and shadows therefore reflect less blue. The contrast between highlights and shadows decreases. In the case of numerous scattered clouds which reflect the sunlight, the shadows will be well lit and only slightly blue. When the sky is obscured by broken up dark cloud, the sky seen through the clear parts is of the deep blue colour usually associated with

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

the sun being low on the horizon early or late in the day.

Three factors play a part in the brightness of the shadow and in their colour.

1. When the sun and sky are the light source with secondary reflections from neighbouring areas.
2. The lighting itself may be very weak from the sky or, on the contrary, may be hardly less brilliant than the directly lit surface if strongly reflecting objects are present.
3. The colour of this secondary reflecting surface is extremely important as it can reflect its own colour into the shadows, perhaps adding a third hue to the mixture already present of the object's colour and the colour of the skylight.

It is therefore essential when composing a colour photograph to avoid these excessive reflections particularly when they are brought about by objects outside the picture area.

In everyday life we see many mild examples of these colour reflections which often add interest to the subject and when working in good weather at midday these effects are translated with reasonable accuracy in a colour photograph. This is not always the case and the use of colour filters is frequently necessary to achieve the desired effect (see Filters).

The manufacturers give instructions with the majority of filters and in most cases these are sufficient. For work of the highest accuracy the colour temperature of the incident light should be measured with a colour temperature meter.

DEFECTS OF COLOUR FILMS

TRANSPARENCIES
(Reversal Films)

Washed-out colours	Over-exposure	Shutter set too slow or aperture too large
Washed-out highlights with other areas correctly rendered	Subject contrast too high together with over-exposure	Less exposure would improve highlights with only slight darkening of the mid-tones and shadows
Highlights correct but mid-tones and shadows lacking detail	Subject contrast too high together with under-exposure	Reverse of above, but results may be acceptable if highlights predominate
	Daylight film; exposed too early in the morning or too late in the evening	Use light blue filter when the sun is low — 2 hours after sunrise or 2 hours before sunset
Overall orange cast	Daylight film exposed in in artificial light	Use the appropriate correction filter
	Artificial light film exposed using old lamps or lamps whose colour temperature is too low	Only use lamps in good condition. Check the voltage. Use a correction filter to make the colour temperature of lamps correspond with that of the film.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Overall blue cast	Daylight film exposed with cloudless blue sky.	Wratten 81A filter.
	Artificial light film used in daylight.	Correction filter.
	Artificial light film used with clear flashbulbs.	Wratten 81C or 81EF filter.
	Daylight film: Blue shadows.	Shadows lit by blue sky use 1A filter.
	Highlights or mid-tones incorrect.	Avoid coloured reflecting areas outside field of view.
	Predominance of green.	Subject placed under trees or green black-and-white filter left on camera.
Colour cast on part of the image	Some parts bluish, others with orange cast.	Mixture of daylight and artificial light — must be avoided.
	Some shadows flat and bluish.	Internal reflections in the lens: always use a lens hood.
	Artificial light film: Colour cast in highlights and mid-tones.	Strongly coloured reflecting surfaces.
	Difference in balance between parts lit by different lamp.	Colour temperature difference between lamps.
	General unsharpness.	Camera movement.
Image unsharp	Some colours sharper than others.	Imperfectly corrected lens.
	Partial unsharpness.	Film not flat in focal plane. Dirty lens.

NEGATIVES

Low density — no shadow detail	Under-exposure.	Shutter too fast or aperture too small.
Image too dense	Over-exposure.	Shutter too slow or aperture too large.
Cyan patches	Film fogged by light coming through red window of camera.	Close the safety cover properly or cover with black tape. Do not leave the camera lying in brilliant sunlight.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

PRINTS		
Flat result, no shadow detail	Negative under-exposed.	Estimate exposure caretully.
Flat burnt-out highlights	Negative over-exposed.	Estimate exposure carefully.
Good highlights but no detail in shadows and dark areas	Subject contrast too high — exposure normal.	Avoid contrasty subjects except when using long-scale negative material.
Burnt-out highlights — good shadow detail	Subject contrast too high with over-exposure.	Expose for highlights if conditions are unavoidable.
Colour cast in part of the image	Extraneous reflections. Mixed lighting.	See under Transparencies.
Colour cast over entire image	Film not balanced for light source.	Use correction filters.

DOCUMENTS AND WORKS OF ART

In recent years there has been an increase in the number of photographic studios and laboratories in industry, public service and private establishments. Photography has become an invaluable tool and recording means which is virtually indispensable. Reproduction, recording and increasing the availability to the public of documents and works of art all fall into the sphere of photography in the various record departments and libraries. Manuscripts, printed books, journals, technical and scientific papers, and works of art can only be recorded beyond dispute by photographic means.

Until the last few years the photographic laboratories have only had black-and-white processes at their disposal — photo copying, microfilms and other photographs of various sizes, and these have given, and are still giving, valuable service.

Now colour photography is gradually taking its place with considerable success. Technicians are now able to make a wide choice from the different brands of stock in both reversal and negative types and in sheet film, rollfilm or 35 mm. format.

Reversal Processes The photographs obtained are viewed by transmitted light. Emulsions are now of such high quality that they can be used even where critical colour fidelity is required. They can also be used as originals from which three- or four-colour separations are made for subsequent photomechanical reproduction. At the same time the transparency serves as a guide to the blockmaker who may find it difficult or impossible to refer to the original — particularly if the latter is a manuscript or work of art.

Use of negative-positive processes As with black-and-white the ideal archive system is to have a negative — in this case in complementary colours. From the negative, any required number of larger or smaller prints can be made. Future increases in the demand for colour reproductions of works of art can be catered for as the negative-positive process enables a virtually unlimited number of either paper prints or transparencies to be made of any required size. The same negative can also be used for the preparation of monochrome copies.

The choice of printing process — transparency or paper print — naturally depends on the intended use of the copy. When required for viewing by a number of people—at lectures or demonstrations, for example — the miniature transparency slide will be the most useful; larger transparencies, on the other hand, will be more useful to the blockmaker when photomechanical reproduction is intended.

Documentation of reports or illustrations for papers will require paper prints. High quality paper prints can also be used as originals in many photomechanical reproduction processes.

Dye transfer This process, which is described elsewhere, can give first quality results — perhaps the best obtainable; it is one of the best print processes particularly when the original photograph is a transparency.

As a precise working method is essential, both in materials and technique, the use of the process in libraries and museums is limited.

It is a very useful process where a number of prints are required, but unfortunately it is only on rare occasions that the demand for a particular copy is great; usually only single copies are required and the sporadic production of prints does not give the most reproducible results.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Equipment The photographic studio or department must have a wide range of equipment with which to handle all types of colour process — reversal, negative-positive and separation negative systems.

The necessity for using precision equipment must be realized before difficulties arise in the production of quality results with obsolete or unsuitable apparatus. Studio equipment should not be used on location; special apparatus should be reserved for outside work.

In the studio heavy equipment is advisable because of its greater stability; the minimum size should be half-plate or 5 × 7 in.

The studio should have a vertical copying stand which can be used for large documents, manuscripts and certain objects. This copying stand should be lit by two light units, each of which contains three 500-watt studio lamps of the Argophot or Nitrophot type or alternatively reflector lamps of the type marketed by Mazda and G.E.C. The latter give excellent results with all flat copy originals.

As light of constant intensity and colour temperature is essential for reproducible and well-balanced results, the electric supply for the lamps should be voltage stabilized. The electric installation should include a master control unit with a voltmeter and manual or automatic voltage regulator. Each lighting unit may be switched from the master panel, and it is essential that each switch should be marked with the description of the unit which it controls. It is extremely important that lamps of different type should not be mixed in the same unit, and lamps of widely differing age should not be used together. The minimum light level should be 400-500 foot-candles, and this should be measured with a foot-candle meter; another valuable measuring instrument is the colour temperature meter (q.v.) whose photocell must be regularly and carefully standardized.

For optimum sharpness throughout the spectrum all lenses should be well corrected; apochromats are to be preferred.

Although the large studio camera is the basic piece of studio equipment, a miniature camera should also be included in the general equipment.

The 35 mm. colour negative, in fact, brings an entirely new approach to document recording as colour microfilming of valuable manuscripts can be carried out at a price very little higher than for black-and-white. The extra expense is easily justified when the film library has at its disposal a negative file from which either colour or black-and-white prints or enlargements can be made. All precision miniature cameras are available with auxiliary equipment for colour document copying and reproduction.

Evenness of illumination Even illumination of the document to be reproduced and complete elimination of reflections are essential to obtain complete fidelity of colour reproduction.

When a large camera is used examination of the image on the ground glass screen can be used to check evenness but if it is necessary to use a miniature camera checking becomes more difficult. It is then necessary to judge the correct orientation of the light sources on the document itself. The first thing to avoid is the presence of specular reflections from the document due to bad placing of the lamps. Even if these reflections do not produce an obvious bright area they may result in local or overall defects if they are received by the front element of the lens and then subject to internal reflections, and this may result in a colour change. The use of a lens hood and coated lens does not prevent this. The different lamps must therefore be placed at an obtuse angle to the subject relative to the camera so that the direct reflections do not come within the field of view. A lamp which is too close to the axis will send reflections back into the lens. Equal illumination is obtained by placing the lamps on either side of the document at the same angles and distances and in the general direction of the centre of the document with slight adjustments to ensure evenness of distribution over the field. The balance of the different sources can be checked by placing an object such as a pencil at the centre of the copy board perpendicular to it, and the shadows resulting from this object should be of equal density and of the same length. To avoid general reflections over the whole image area the document should be placed against a dark neutral background so that no colour cast results and so that light readings are taken only on the object, giving greater precision.

Considerable trouble should be taken initially to ensure evenness of illumination and elimination of reflections. It should also be borne in mind that the reproduction of a coloured document is not the same thing as a still life photograph in that all the colours of the reproduction can be compared with those of the original directly.

DUXOCHROME PROCESS

This process, which was brought out in 1929, combines very successfully the different methods of the carbon and carbro processes by using:

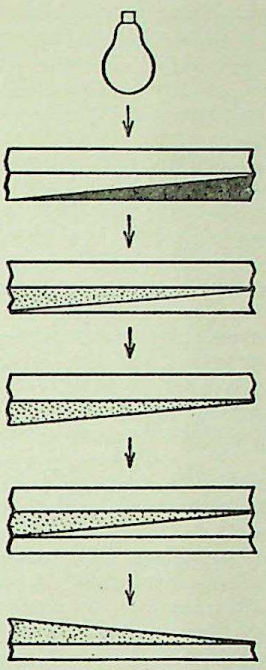
1. Photographic emulsions for exposing the separations instead of the far less sensitive bichromate sensitizer.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

2. Simple transfer methods with correction processes which enable the colour balance of the image to be adjusted. This is the first time that these have been disclosed in this type of process. The basic process is as follows.

The gelatin reliefs are obtained from sensitive layers coated on to transparent supports and contain yellow, magenta and cyan pigments. The emulsion is sensitive to blue light and also contains a fugitive yellow dye to limit the penetration of light and thus assist the formation of a relief.

The first stage is to print the separations corresponding to yellow, magenta and cyan through the base of the films and after a tanning development stage obtain reliefs by bleaching, fixing and washing in warm water. The reliefs then are made up of pigmented gelatin only. The final image is obtained by transferring the three reliefs on to a gelatin-coated paper base after stripping from the transparent supports. Before transferring the reliefs a certain amount of reduction of density of one or more of the images can be achieved by further washing to bring the three into balance. The order of transfer is yellow, magenta and then cyan and this is dictated by the transparency of the pigments (see Fig. 1).


1. Separation negative.
2. Printing on to pigmented tissue having transparent support.
3. Tanning development, bleaching, fixing, hot water 'development'.
4. Final transfer on hardened gel-coated paper.
Fig. 1.

DYE TRANSFER PROCESS (Kodak)

This process is typical of the imbibition processes comprising the preparation of three separations in the form of gelatin reliefs which can take up dye solutions and then transfer them in reverse on to a paper base to give the final image by superimposing three transfers. The first step is to prepare three-colour separations either directly from the original or from a transparency. Also required are matrix films, dye and buffer solutions, mordanted paper and various other solutions which are used to correct the contrast of the transferred image during transfer, to reduce the density of the print and to wash the matrices for further transfer.

Kodak matrix film is primarily sensitive to blue or blue-violet and contains a yellow dye to limit the penetration of light into the emulsion depending on the density of the separation negative and the colour of the light used for printing. The Kodak transfer paper has a gelatin layer which is mordanted so that dye is taken up from each of the three matrices.

Outline of the process As the matrix film is only sensitive to blue light it can be safely handled in the darkroom with red light. The three separations are printed using an enlarger and it is essential that no change should be made in its adjustment between the printing of the three matrices. Ordinary white light is used for this together with a Wratten 2B filter. Tanning development is carried out for 2 min. at 68°F. The films may be developed either together or separately using any suitable agitation method. The developer is diluted according to the contrast required. After development the developer is quickly poured off and a small amount of stop bath at 68°F is poured into the dish which is agitated constantly for 1 min. White light may be turned up after the film has been in the stop bath for 30 sec. The stop bath is poured off and the film is hot-water developed at a temperature between 110° and 140°F. The hot water is changed several times until it no longer becomes cloudy due to the presence of unhardened emulsion washed off the matrix film. After hot water washing the relief is rinsed in water at 60°–70°F to harden the gelatin relief. The matrices are then dried and each should be hung from the same corner to avoid unequal stretching or shrinking and it is also advisable to wipe the back of each film carefully with a chamois or small sponge to avoid local deformation caused by the presence of water droplets on the back of the film. Great care must be taken throughout to give each matrix exactly the same treatment to avoid dimensional changes which will make transfer in register difficult or even impossible.

Registration The cyan matrix is placed gelatin-

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

face down on a viewing box which has a horizontal plate-glass viewing surface. The matrix is fixed to the glass with transparent tape. The magenta matrix is then superimposed over the cyan one in exact register and is similarly taped down by its four corners. The yellow matrix is similarly treated. Register should be checked with a magnifier using fine detail; with the aid of a print trimmer or a knife and straight edge, two adjoining edges of the three films are cut at the same time. These edges are used as register guides on the transfer blanket, being pushed up against three stops fixed to the blanket. The matrices are prepared for imbibition by soaking each one separately for one to three minutes in a dish containing water at 68°F. This ensures equal stretching of the three matrices and hence assists registration, especially in the case of matrices which have been stored for some time.

The matrix corresponding to the red separation is dyed cyan (blue-green), that from the green filter negative is dyed magenta and the one from the blue filter negative is dyed yellow. Each matrix is treated in the dye bath for a fixed time. The dishes containing the dyes must be frequently agitated to obtain even dyeing and transfer.

Whilst the matrices are being dried, soaked and dyed, several sheets of transfer paper are treated for about 30 min. in the paper buffer bath. This bath adjusts the acidity of the paper to the required value for transfer. The cyan matrix is removed from the dye solution, drained and treated for 1 min. in 1 per cent acetic acid. Agitation should be continuous and the solution is discarded after use. The step removes excess dye and also buffers the matrix to the correct acidity for transfer. The matrix is again treated in 1 per cent acetic acid and is left in this solution whilst the paper is placed in position.

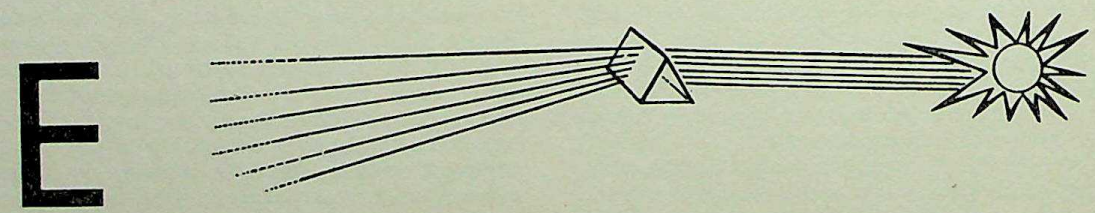
The paper is removed from the buffer bath and placed on the transfer table and is carefully squeegeed to remove excess liquid.

The cyan matrix is removed from the second acid rinse (which can be re-used) and is drained for only 2 or 3 sec. It is then put on to the transfer blanket gelatin face uppermost and the two trimmed edges are moved up to the three stops on the blanket. The blanket is then lowered on to the transfer paper and the matrix and paper are pressed together by means of a roller squeegee. A single stroke of the squeegee is all that is required. After a few minutes the transfer is complete and the matrix is stripped off the paper. The magenta and yellow matrices are similarly treated.

After each transfer the matrices are cleaned by placing them in matrix regenerator solution for at least 30 sec., followed by rinsing for at least 1 min. in running water to remove completely any residual regenerator. Before re-dyeing the matrices it is advisable to wash the matrix further in distilled water. Each matrix must be cleaned in this way after each transfer to facilitate the production of additional prints.

The prints must be blotted between suitable paper before drying and may be glazed in the usual way provided the glazer is not too hot; they can also be dry-mounted.

Although the dye transfer process enables very high quality prints to be made, it should be borne in mind that it is a lengthy and critical process and cannot compete in many ways with colour development processes which are quicker, more stable and more readily adapted to commercial mechanization.



EASTMANCOLOR

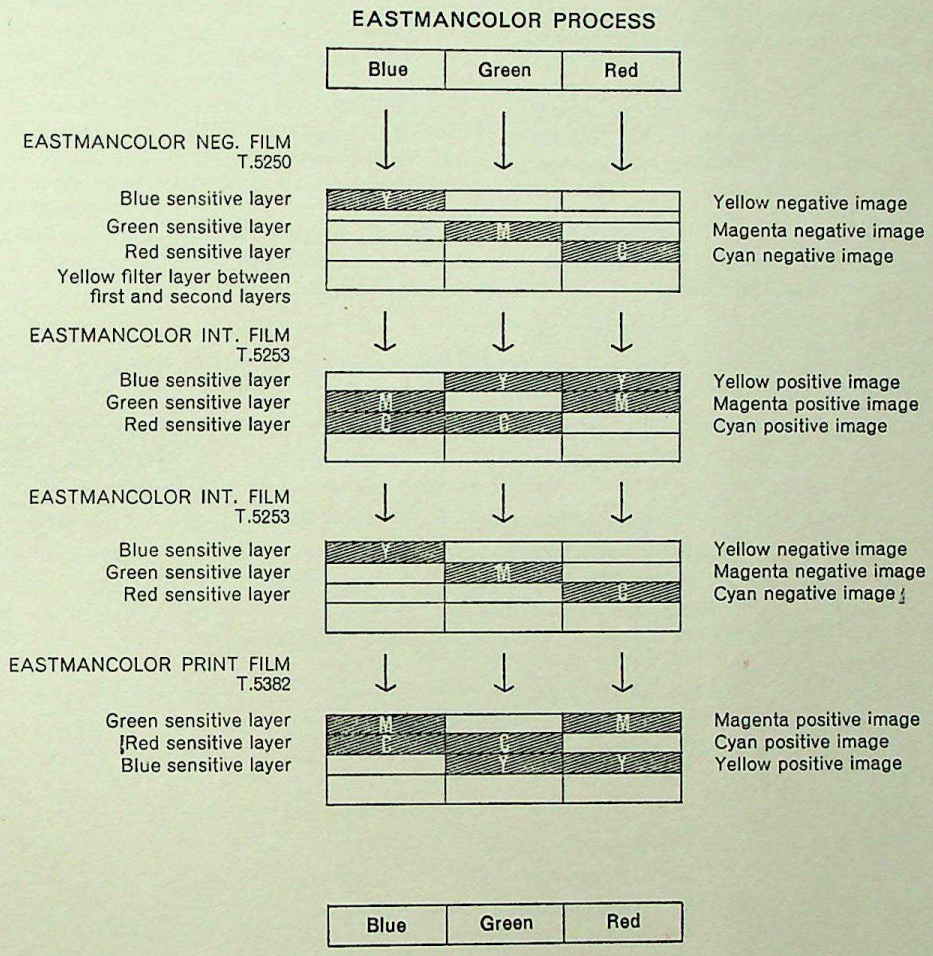
In 1950 the Eastman-Kodak Company marketed a negative stock (Eastmancolor Negative Film type 5247) together with a print stock (Eastmancolor Print film type 5381). In 1951 these were followed by a separation film type 5216 and an internegative type 5243. Several films were produced at the time in which one or all of these stocks were used. However, full use of the process was not made until a negative film of tungsten balance for use with studio lamps was introduced. At the same time, changes were made to the internegative and positive films which resulted in an improvement in quality; this resulted in three films being offered for sale — Eastmancolor negative type 5248 for

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

tungsten light, internegative film type 5245 and positive film type 5382.

In 1918 the process was modified by the introduction of Eastmancolor Intermediate film type 5253 thus eliminating the need for separation positives. Type 5253 film is used to make both an intermediate colour positive and from this a duplicate negative. An improved and faster Eastmancolor negative, type 5250, now replaces type 5248.

Choice of colours, make-up, costumes, etc
Before starting on a production it is advisable to carry out careful tests to determine the way in which different make-up, materials and pigments are reproduced. The results of these tests should be carefully evaluated and recorded for future reference. The rendering of neutral greys and of skin tones is particularly important as it is on these areas that printing characteristics are judged.



EKTACHROME
(Reversal colour film)

The name Ektachrome covers a number of types of reversal colour film manufactured by Kodak intended for user or trade processing. The films may be conveniently classified according to the processing procedure — E-1, E-2 or E-3. Films of one group should not be processed in the solutions intended for another group.

Process E-1

Ektachrome Sheet film, Daylight type, 12 ASA (can be rated at 6 ASA with 3,200°K lamps using 80B filter)

Ektachrome Sheet film, Type B (3,200°K), 10 ASA (can be rated at 6 ASA with daylight using an 85B filter)

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

(*Note.* Process E-1 films will eventually be replaced by Process E-3 films)

Process E-2
Ektachrome Roll and 35 mm. film, Daylight 32 ASA
Ektachrome Roll and 35 mm. film, Type F (clear flash)
16 ASA to daylight with 85C
16 ASA to Photoflood with 82A
12 ASA to 3,200°K lamps with 82C
High Speed Ektachrome film, Daylight, 160 ASA (can be rated at 80 ASA with Photoflood lamps using an 80B filter)
High Speed Ektachrome film, Type B (3,200°K) 125 ASA
(*Note.* The effective exposure index of H.S. Ektachrome can be doubled if the first development time is increased by 3 min.)

Process E-3
Ektachrome Roll and Sheet film, Daylight, 50 ASA
Ektachrome Sheet film, Type B (3,200°K), 32 ASA
25 ASA Photoflood with 81A
Clear flashbulbs with 81C

Processing Ektachrome film Three different processing kits are available — E-1, E-2 and E-3. The E-2 is primarily intended for amateur use and is therefore available in kits to make up 600 cc. solutions. The E-1 and E-3 processing kits are primarily intended for professional use.

Amateur photographers intending to use the E-2 process should bear in mind the need to maintain the temperature of the first developer to within $\pm\frac{1}{2}°$ of 75°F: the tolerance for the remaining operations is ±2°F. Full instructions are supplied with each kit. The following table gives the sequence of operations.

Process E-3
This follows basically the same procedure as for the E-2 process except for step No. 12 Fixing bath where the recommended time is 4 min.

SUMMARY OF PROCESSING PROCEDURE FOR EKTACHROME FILM, E-2 PROCESSING CHEMICALS

STEP		REMARKS	TEMP. °F	TIME MIN.	TOTAL MIN. AT END OF STEP
1	First developer	Agitate as recommended	75 ± ½*	10	10
2	Rinse	Running water; agitate as recommended	73–77†	1	11
3	Hardener	Agitate as recommended	73–77	3	14
		Remaining steps may be done in normal room lighting			
4	Wash	Running water	73–77	3	17
5	Reversal exposure	Films must drain for at least 1 minute before colour development		Reset timer to zero	
6	Colour developer	Agitate as recommended	73–77	15	15
7	Wash	Running water	73–77	5	20
8	Clearing bath	Agitate as recommended	73–77	5	25
9	Rinse	Running water	73–77	1	26
10	Bleach	Agitate as recommended See warning on label	73–77	8	34
11	Rinse	Running water	73–77	1	35
12	Fixing bath	Agitate as recommended	73–77	6	41
13	Wash	Running water	73–77	8	49
14	Stabilizer	Agitate as recommended See warning in instructions	73–77	1	50
15	Dry	Remove film from reels	Not over 110°F (43°C)		

Note: Agitation is for 15 sec. on first immersion and 5 sec. after every minute thereafter.

*24 ± ¼°C †23–25°C

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

EKTACOLOR (Negative colour film)

Ektacolor sheet film is a colour negative material manufactured by Kodak having similar characteristics to Kodacolor film but designed specially to suit the needs of the professional worker. Coloured couplers in the film provide automatic colour correction and make excellent quality possible in colour reproduction without supplementary masking. There are two types, each intended for use over a specific range of exposure times.

Ektacolor Sheet Film, type S,
25 ASA to daylight with 85C filter.
20 ASA to Photoflood with 82A filter.
16 ASA to lamps of 3,200°K with 82C filter.

The film is designed for use at exposure times of $\frac{1}{10}$ sec. or shorter. It can be exposed with clear flashbulbs without a filter or with electronic flash with an 85C filter.

Ektacolor Sheet Film, type L,
20 ASA to daylight with 85B at $\frac{1}{5}$ sec.
12 ASA to Photoflood with 81A at 5 sec.
25 ASA to 3,200°K lamps, no filter, $\frac{1}{5}$ sec.
16 ASA to 3,200°K lamps, no filter, 5 sec.
10 ASA to 3,200°K lamps, no filter, 60 sec.

The film is designed for use at exposure times of $\frac{1}{5}$ to 60 sec. with 3,200°K lamps, or with appropriate filters to daylight or with Photoflood lamps. The effective exposure index varies with the length of the exposure.

Processing Ektacolor Ektacolor negatives should be processed using the kits supplied by Kodak Limited with the following sequence of operations.

EKTACOLOR PROCESSING TABLE — PROCESS C.22

STEP		REMARKS	TEMP. °F	TIME MIN.	TOTAL MIN. AT END OF STEP
1	Develop	Agitate as recommended	75 ± ½	14	14
2	Stop bath	Agitate as recommended	73–77	4	18
3	Harden	Agitate as recommended	73–77	4	22
		Remaining steps may be done in normal room lighting			
4	Wash	Running water	73–77	4	26
5	Bleach	Agitate as recommended	73–77	6	32
6	Wash	Running water	73–77	4	36
7	Fix	Agitate as recommended	73–77	8	44
8	Wash	Running water	73–77	8	52
9	Remove water droplets	Rinse in diluted Kodak 'Photo-Flo' Solution	73–77	1	53
10	Dry		Not over 110°F		

EXPOSURE

Exposure is measured as the product of intensity and time.

The exposure time, in its true sense, is the exposure duration which is most suitable for producing an image of the desired characteristics taking into account the diaphragm of the lens and the properties of the emulsion.

The illumination is the luminous flux received by a surface. It is measured in lux under the metric system; 1 lux is the light received by an area of 1 m² at a distance of 1 m. from a metric candle (see Photometry).

Illumination by various light sources

	Lux
1 candle at 1 m.	1
2 candles at 0·40 m.	10
1 40 watt lamp at 1 m.	50
1 Photoflood at 1·70 m.	250
6 lamps at 2 m.	1,200
Sunset	5,000
Shadows in summer	8,000
January sunshine 9 a.m.	10,000
March sunshine at midday	60,000
June sunshine at midday	80,000

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

The luminance of a surface is expressed as the product of the intensity of light reaching the surface and the reflection factor and is expressed in 'blondels'.

Brightness of natural objects in June sunlight

	Blondels	*Brightness ratio*
Tree trunk in shadow	150	1
Green grass in shadow	600	4
Green grass in sun	7,000	45
Sunlit foliage	3,200	21
Foliage, shaded side	600	4
Bare earth in sun	6,700	41
Clear sky at horizon	9,000	60
Clear sky close to sun	100,000	666
Sunlit clouds:		
near the horizon	20,000	133
at 45° to sun	30,000	200
at 30° to sun	50,000	333
at 10° to sun	100,000	666

Subject contrast In practice the reflection factor of a surface rarely exceeds 95 per cent and is usually greater than 1 per cent.

An evenly-lit subject can therefore never exceed this range.

If a sheet of white paper, half of which has been painted with Indian ink, is evenly illuminated, the white parts reflect only 90 per cent of the light and the black part reflects 3 per cent; the brightness ratio is 90 to 3, or 30 to 1.

Lighting contrasts A subject consisting entirely of material of the same reflection factor but with different areas oriented in different directions to the light source has a brightness ratio which is influenced by many factors.

This ratio is the lighting ratio which effects the subject brightness range and the accuracy with which the subject can be produced.

Thus a white surface reflecting 90 per cent of the incident light will, in bright sunlight, receive 80,000 lux and reflect 72,000 blondels. At the same time a black surface capable of reflecting 2 per cent of the light and situated in shadow where it receives only 8,000 lux will merely reflect 160 blondels.

The extreme subject brightness range is therefore 450:1.

On the other hand, if the white surface is in shadow it will reflect only 7,200 blondels whilst the black surface in sunlight will reflect 1,600 blondels.

In this case the brightness range is reduced to 4·5 to 1.

Exposure latitude The photographic emulsion can only record accurately a fixed exposure range. The correct exposure is recorded only on the straight part of the characteristic curve, the brightness range of the subject being such that the exposure range of the emulsion is not exceeded.

Exposure latitude is not a characteristic of the emulsion but relates to the brightness range of the subject and the exposure range of the emulsion. Fast emulsions for black-and-white photography have an exposure latitude close to or exceeding 1,000:1 and therefore provide considerable exposure latitude for most subjects; a range of exposures can be made, the shortest of which does not have its shadow areas in the under-exposed region whilst the longest suffers from no over-exposure of the highlights.

For example, a negative emulsion may have an exposure range of 900:1 and if the image produced by a bloomed lens has a brightness range of 80:1 the ratio of the two is 11:1 corresponding to four diaphragm stops, that is from *f*/4 to *f*/11.

This calculation, which is readily made for black-and-white work, is not so straightforward in its application to colour photography; other factors must be taken into account.

Exposure tolerance Reversal materials have only a small exposure tolerance; in black-and-white as in colour photography the opaque part of the image corresponds to the clear part of the negative (see Reversal Processes).

In colour work some materials cannot be under- or over-exposed by more than half a stop without showing noticeable lack of colour fidelity; other processes are more tolerant. Even low contrast subjects which in theory have a wider exposure latitude, cannot in practice make use of it as over-exposure produces washed-out thin transparencies whilst under-exposure results in photographs which, though denser and brighter, are equally incorrect.

Range of colour emulsions Older type colour emulsions had a very short exposure range, that is they could only record a relatively small subject brightness range. Subjects which have a wide brightness range may tend to be recorded with burnt-out highlights or solid black shadows; the recent tendency is towards materials having a softer gradation and this enables subjects of wider brightness range to be faithfully reproduced or narrow range subjects to be photographed with an increase in exposure latitude.

Reciprocity failure In current photographic practice the same exposure may be given varying

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

the two factors, exposure and time; if their product is constant the reciprocity law is followed. In practice any departure from an average exposure time (extremely brilliant lighting and short exposures or dim lighting and long exposures) results in a drop in photographic efficiency; there is a failure of the reciprocity law which must be taken into account in colour photography where precise exposures are necessary. This effect may be noticed using short-duration electronic flash. The loss of efficiency is very difficult to measure but generally requires an increase in aperture of about half a stop when electronic flash is used (see Reciprocity).

Aperture and shutter speed The variation of exposure by means of the aperture and speed settings is made by increasing one and decreasing the other. Shutter speeds are generally marked in steps, each of which is approximately double or half the adjoining one, and diaphragm apertures are calibrated on a scale following the same ratio but are generally more exact. Many lenses have the following steps.

Stop	*f*/2	2·8	4	5·6	8	11	16	22	32
Speed	1/500	1/200	1/100	1/50	1/25	1/10	1/5	1/2	1 sec.

The lack of exactness in this relationship is of no great consequence in black-and-white work where the exposure latitude of the material is so great; this is not the case however with colour materials, particularly reversal films whose scale is extremely short.

A different and more exact scale of shutter speeds has been adopted by most manufacturers for their new shutters, particularly those in which the iris and speed settings are linked.

With this type of shutter the diaphragm and shutter speed are linked and set to an 'exposure' or 'light' value, given by the exposure meter. If an alteration is made to the shutter speed, the aperture is automatically compensated, and vice versa, without any change being made in the basic exposure.

The speeds used are: 1/500, 1/250, 1/125, 1/60, 1/30, 1/15, 1/8, 1/4, 1/2, 1 sec.

The approximation is appreciably closer and exposures are substantially even.

The product of brightness and speed is constant. Displacement of the speed scale relative to that of the aperture or brightness changes only this product.

The linking of diaphragm and shutter speed enables equal exposures to be made between 1 sec. at *f*/4 and 1/500 at *f*/22, an average exposure giving a choice between 1/125 at *f*/4 and 1/4 at *f*/22. Naturally by releasing the linking system any aperture and any shutter speed can be selected at will.

The exact exposure required for a fixed part of the subject cannot be obtained from information given in tables, however accurate these may be, based upon average subjects and groups. It is essential to work by measurement and only an exposure meter can give the required accuracy.

Exposure meters Photo-electric exposure meters are the most widely used and convenient type. The basic principle of these meters is as follows: a photo-electric cell is connected to a galvanometer whose scale is graduated to show the amount of light and this in turn is used to indicate the correct exposure. In recent types a direct reading of aperture and speed is often given and these meters may also include an exposure value scale.

There are two basic types of photo-electric meter; those measuring the light reflected by the subject and those measuring the light falling upon the subject.

Reflected light exposure meters The photocell is constructed so that it receives light directionally through an angle corresponding to the angle of view of a normal lens, that is, about 50°. It is pointed towards the subject from the camera position and measures the average amount of light reaching the film from all parts of the subject. This amount of light depends on two factors: the amount of light reaching the subject and the amount of light reflected by it.

Two surfaces of different reflecting power and receiving differing amounts of incident light may have the same brightness. Thus a white surface

Exposure ratios		1	2	3	4	5	6	7	8
Brightness		1	2	4	8	16	32	64	125
Aperture		*f*/2	2·8	4	5·6	8	11	16	22
Shutter speed		1/125	1/60	1/30	1/15	1/8	1/4	1/2	1
	or	1/500	1/250	1/125	1/60	1/30	1/15	1/8	1/4

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

which reflects 90 per cent of the light, lit by a 10-candle-power source, will reflect 9/10ths of the incident illumination, that is 9 candles. On the other hand a black surface which reflects 10 per cent lit by a 90-candle-power source will also reflect 9 candles.

The reflected light meter will show the same brightness for the two surfaces which will be reproduced photographically at the same density.

It follows that if the two surfaces are to be reproduced according to their reflecting power of 9:1 the dark surface must receive 1/9th the exposure.

But a photograph does not consist only of a single uniform and evenly lit surface.

If instead of having two separate areas, as in the previous example, a combined reading is taken of both areas the reading will depend upon the relative distribution of the black-and-white area.

With equal black-and-white areas the white reflecting 90 per cent and the black reflecting 10 per cent, an average reading of 50 per cent will be obtained; if the proportions are $\frac{1}{4}$ black and $\frac{3}{4}$ white the measurement will be 70 per cent reflection or 30 per cent reflection in the converse case. In colour photography discrepancies of this magnitude are excessive.

Brightness measurement An exposure based upon the total reflection method, which has just been described, is by no means infallible in all cases. The presence of large highlight or shadow areas will introduce severe errors; the scenes should have an average brightness of approximately 1/5th that of a uniformly lit white area reflecting 90 per cent of the light.

The reading given by the meter is the mean of the differently lit areas and it will be the same for a subject whose range is from 1 to 9 (that is 250:1) as for a subject whose range is only from 4 to 6 (that is 4:1).

Correspondence between:

Log. brightness	1	2	3	4	5	6	7	8	9
Brightness	1	2	4	8	16	32	64	125	250

A very short range emulsion will in the first case render the mid-tones with reasonable accuracy but the shadows will be in the under-exposed region and the highlights will be over-exposed.

Measurement of the extremes of brightness is necessary to determine the brightness range which controls the correct colour rendering.

Photo-electric meters are calibrated to measure a scene of average brightness corresponding to 1/5th of the reflection of a 90 per cent reflecting white surface, that is 18 per cent of the incident light.

Whatever the brightness of each individual scene the exposure meter gives an exposure which would in all cases produce the same average density. A measurement taken of the whole subject gives the average brightness, the light and dark areas being reproduced as low and high densities without reference to their actual brightness.

It is therefore necessary to increase the exposure if the subject is very light, or decrease it for a very dark subject.

Thus a snow scene with no appreciable shadow area requires an increase of 1 to $1\frac{1}{2}$ stops of that indicated by the meter, whereas a subject taken in deep shade will require a reduction in exposure of about $\frac{1}{2}$ a stop. If this is not done the first subject, which should be very light, will be rendered too dark, whilst the second will lose its low key character.

In colour photography all colours must be rendered correctly relative to white even if the subject contains no white. It can generally be said that all photographs will be accurate if whites are rendered with the correct brilliance and purity provided, in all cases, that the subject range does not exceed the emulsion range.

The exposure must therefore be based upon the highlights bearing in mind the brightness range of the subject.

Highlight measurement The method of highlight measurement consists of replacing the subject with a sheet of white paper and ignoring the hypothetical average subject brightness of the previous method.

For use with this method, Kodak supply a card. The white surface of the card reflects 90 per cent of the incident light whilst the other, a neutral grey, reflects 1/5th of this amount, i.e. 18 per cent.

Each measurement of the white area requires an increase of five times the indicated exposure, whilst measurements taken on the neutral grey card should be correct for average subjects and should require no more than plus or minus half a stop correction.

In many cases accurate reproduction of one colour is essential. For example, skin tones in portraiture. The model will not necessarily be in surroundings of average brightness and in order to stand out may be placed against a very light or very dark background; measurements taken in the first case will be too low and too high in the second, resulting in dark or washed out skin tones.

The measurement must be made close to the centre of interest so that it is the only object included in the 'angle of view' of the meter. The exposure is then increased by half a stop. A measurement on the hand instead of the subject should only be made in an emergency, as differences in colour which are hardly noticeable to the eye may make such readings inaccurate.

Furthermore the sensitivity of the photocell is not the same as that of the eye and the substitution of a grey card for the subject will rule out this possible source of error.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Incident light meters Actually, the use of the reflecting white surface is a return to the method of measuring the light reaching the subject. This measurement is given directly by incident light exposure meters. These are in fact light meters graduated in terms of exposure.

As incident light meters are not intended to measure the reflected light they are used from the subject position and directed towards the camera and receive the same light as the subject provided they are capable of integrating the whole of the light received through a complete hemisphere.

As the subject does not normally consist of a single plane at right angles to the camera, but of a multitude of planes at different angles, the receptor of the incident light meter usually consists of a hemisphere or specially shaped three-dimensional form of translucent material which integrates light through 180°.

Frontal light illuminates the whole of the hemisphere whilst side-lighting illuminates only a proportion of the hemisphere corresponding to the illuminated portion of the subject. Thus incident light meters of this type measure the effect of a single light source or of multiple sources with equal precision.

Incident light measurements make no allowance for subject lightness or darkness and if the subject corresponds to the average of 18 per cent reflection no correction need be made to the calculated exposure. Only extremely light or extremely dark subjects require an alteration in exposure amounting to a decrease or increase of half a stop respectively.

An ordinary exposure meter can be converted for incident light readings by covering the photocell with a piece of translucent material; after careful standardizing it will then be sufficiently accurate for black-and-white work though not good enough for colour.

Some of the better types of exposure meter are however, manufactured for use as incident light meters as well as reflected light meters by using the manufacturers' attachment.

Photoflood lamps Measurements made in artificial light are made by the incident light method using either an incident light meter or the white card in conjunction with a reflected light meter.

To obtain accurate readings it is essential that the incident light meter or the white card should be placed directly opposite the camera lens and perpendicular to its axis when measurements are made. The meter or card should be as nearly as possible in the subject position as slight errors in the lamp-to-subject distance result in considerable errors in the measured intensity (following the inverse square law).

The corrections which must be applied to the meter calculations according to the key of the subject are similar to those which must be applied in daylight.

The use of an incident light meter enables the relative strengths of key lighting and fill-in to be measured to give the desired lighting contrast (by moving lamps towards or away from the subject). It must be remembered that the lighting range should not exceed 4:1 otherwise an unexpected contre-jour effect will be obtained giving poor colour rendering.

Flashbulbs The output of these lamps cannot of course be measured and exposures are therefore calculated on the basis of the lamp-to-subject distance and the aperture using a 'guide number' which is influenced by the type of bulb and the film speed.

To find the aperture required the guide number is divided by the lamp-to-subject distance; the quotient is the aperture to be used.

Thus with a lamp and film combination having a guide number of 45 working at a distance of 10 ft. the aperture required will be $f/4{\cdot}5$.

If two or more lamps are used together the calculation is carried out as for one lamp and the lens is stopped down by one stop for each doubling of the number of lamps.

Thus one lamp at 10 ft. requires an aperture of $f/4{\cdot}5$; two lamps at 10 ft. give double the light and therefore require half the exposure, i.e. $f/6{\cdot}3$.

EXTERIORS

Rather than attempt to treat separately and in detail the many types of exterior subject, it is deemed preferable to concentrate on the general conditions necessary for good colour photography.

Light The light is almost exclusively daylight (q.v.) in which direct sunlight and the diffuse skylight both play their part. The colour of the light is influenced by the time of day, the direction of the sunlight and the weather. The lighting contrast and level are also affected by these factors. The colour of objects can only be defined in terms of incident light of known characteristics, especially direct sunlight with a little surrounding sky light whose colour temperature is about 5,600°K. Any change in the proportion of the various sources of light alters the colour of the light and hence the colour of various objects. A white surface which reflects all the blue, green and red light appears yellow if the amount of blue light is reduced and

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

green if there is an appreciable reduction of red light. A yellow object appears greenish is there is an excess of blue light.

Colour This colour cast extends through the whole range of colours of the subject. An excess of blue in the composition of the light, as is frequently found by the sea or where there is a very strong blue sky, raises the colour temperature and makes the yellows greenish and the reds more violet. All warm colours become more dull and by contrast the blues and blue-greens appear brighter. The opposite effect occurs when the sun is low in the sky and the light has less blue in it than red and green. As a result this brings about a yellowish cast. A colour cast may not be due to an excess of a certain colour in the total illumination. Colours which give a local colour cast are produced by reflections, for example areas which are only lit by the blue sky or which are indirectly lit by reflections from a nearby coloured object.

Although from the aesthetic viewpoint the colour casts may not be of prime importance, in practical colour photography it is desirable to know the reasons for certain casts which may be unpleasant.

Colour casts and local reflections may not be easily seen on the subject itself. For example the effect of invisible ultra-violet rays do not produce any visual sensation and variations in colour with the time of day are not sufficiently noticeable to attract the photographer's attention. Both effects can however produce defects in the colour photograph which can be foreseen and allowed for (see Faults).

Daylight emulsions which are balanced for 5,600°K will record the changes produced by variations in the colour temperature of the light. An apparent lack of balance only appears so because the light is appreciably different from that to which we are accustomed, i.e. sunlight in the middle of the day. The reproduction of variations caused by time of day and weather conditions is mainly a matter of taste and the necessity to please most people.

Apparent lack of balance is only due to colour interpretation based on the appearance of objects under customary viewing conditions — the standard being noon sunlight. By adhering to this convention — which is only apparent fidelity — many of the subtle effects in outdoor colour photography due to climatic variations are lost. The whole question is a matter of taste, and perhaps of pleasing the majority of viewers. In certain cases a colour cast may harmonize two adjacent colour areas which might otherwise appear unpleasing.

The attractiveness of a colour photograph depends to a great extent on the photographer's discretion in the balance and arrangement of the colour masses and in their relative dominance. A landscape, like any other subject, is not a colour chart — it has its centre of interest which controls the number and relative importance of the other coloured objects which are included.

This involves the need to build up the composition around a bright colour which is emphasized when surrounded by its complementary. The latter must, however, be suppressed, darkened or lightened if it occupies a larger area than the principal object. The possibility of doing this usually occurs outdoors. It is rare that masses of foliage, broad areas of country or buildings are not available for use as a background against which the principal subject can be effectively set.

The position which a colour takes in the whole composition has a great bearing on the effect of depth. If colours are arranged in their spectral order with red at the bottom there is a sense of the blue and violet at the top receding; the opposite effect is produced by inverting the colours with the red at the top. This explains why a red patch in the background appears to stand out whilst a blue foreground object even though vivid tends to recede.

In this way aerial perspective caused by bluish distance is lost if an ultra-violet filter is used which suppresses this blue cast.

Contrasts The opposition, or contrast, of colours comes into the field of taste and interpretative ability. They will be rendered correctly only if the whole of the subject is uniformly lit, and it is rare that the range from the lightest to the darkest colours can be accommodated by the short range of the colour emulsion. For this reason the beginner is advised to commence his colour work using flat shadowless lighting.

When the influence of lighting contrast is brought in, parts of the subject will be in deep shadow and others will be brilliantly lit. This may result in the lighting contrast exceeding the 4:1 range which is recommended, and theoretically necessary with, for reversal materials. In practice however, shadow detail is sacrificed by exposing for the well-lit areas; correct reproduction is critical here, but relatively unimportant in deep shadow.

This general rule can only be ignored in special cases; when the highlights are only present as small areas in a predominantly mid-tone or sombre subject — for example, under trees the highlights are merely spots of light filtering through the foliage, and exposure for the shadows is also necessary with contre-jour effects if an accentuated silhouette is not to be obtained. With contre-jour effects, where the brightness range inevitably exceeds that of the emulsion, care should be taken in the choice of colours which, when incorrectly reproduced, may not tone well together.

DALMATIAN IKON — photograph by E. Feiger in existing daylight with a Retina Reflex camera and Kodachrome film. ▶

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Filters Reference has already been made to filters. The range available for use in colour photography is very great (see Filters). Apart from the conversion filters such as the Wratten 85 and 85B used with 3,400°K and 3,200°K tungsten films for daylight, and the haze-cutting and excess blue suppressing ultra-violet filters, the rest are of no use if the subtleties of lighting variations — often the most attractive features of colour photographs — are to be recorded.

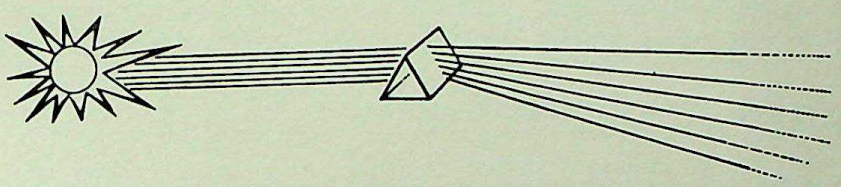
It must never be forgotten that colour balance is based upon obtaining a reproduction which matches the subject as nearly as possible under normal viewing conditions. Whilst this must be interpreted in one way when reproducing documents, and in scientific work, etc, where a wide range of correction filters must be available, a different argument may be used for exteriors where it is the effect of lighting of a particular quality which may turn an ordinary 'view' into a picture.

Exposure The limited latitude of colour materials demands greater care during exposure than for black-and-white. The following points should be remembered:

1. The relatively slow speeds of some colour films limits the available shutter speed range.
2. The material may only give accurate reproduction over a limited speed range.
3. The shutter speeds and lens apertures are not necessarily the effective settings; shutter efficiency usually drops at higher speeds and lenses of different construction have different transmissions at the same *f*-number (*T*-stop calibration overcomes this last error).

It is therefore advisable to work at a set speed (1/50 sec.) wherever possible, and to control the exposure by varying the diaphragm according to the exposure meter indication. The latter should first have been standardized with the particular camera and film.

This speed is sufficient to stop moderate movement; it is enough to avoid camera shake (a slower speed would necessitate a stand), yet with most small cameras it usually enables a small enough stop to be used to give adequate depth of field.



F

FERRANIACOLOR
(Negative-positive process)

Ferraniacolor negative film has the same speed and balance as the reversal type. An artificial light type balanced to 3,200°K (Nitraphot, Argophoto, etc) is also available. As with the reversal film, manufacturer's kits are used for processing. The following is a summary of the processing sequence:

FERRANIACOLOR NEGATIVE PROCESSING PROCEDURE

STEP		REMARKS	TEMP. °F	TIME MIN.	TOTAL MIN. AT END OF STEP
1	Colour development	Agitate every 15 sec. for the first 2 min., and then every minute	65 ± ½	8	8
2	Wash	Preferably spray wash	65	15	23
3	Bleach	Hardening also takes place in this bath	65	5	28
4	Wash	White light may now be switched on Wash thoroughly	65	5	33
5	Fix	Complete removal of silver salts	60–65	5–8	38–41
6	Wash	Spray wash	65	15	53–56
7	Dry	after sponging	95°F max.		

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

FERRANIACOLOR (Positive film)

Ferraniacolor positive film is designed for use in conjunction with the negative material, for the production of transparencies for projection or direct viewing. Prints can be made by contact or by enlargement by similar methods to Ferraniacolor paper. The same method of correction during printing by the use of filters is used. The following is a summary of the processing sequence:

FERRANIACOLOR POSITIVE PROCESSING PROCEDURE

STEP		REMARKS	TEMP. °F	TIME MIN.	TOTAL MIN. AT END OF STEP
1	Colour development	Agitate every 15 sec. for first 2 min., and then every min.	65 ± ½	7	7
2	Wash	Spray wash	65	15	22
3	Bleach	Hardening also takes place in this bath	65	5	27
4	Wash	White light may now be switched on. Wash thoroughly	65	5	32
5	Fix		60–65	5–8	37–40
6	Wash	Spray wash	65	15	52–55
7	Dry	after sponging	95 max.		

FERRANIACOLOR (Reversal process)

Ferraniacolor reversal film is of the usual three-layer subtractive type with the couplers incorporated in the emulsion. It is capable of good reproducibility of results and the processing is quite straightforward. Processing is carried out using the manufacturer's kits. The film is balanced for use in daylight or with electronic flash or blue flashbulbs. Colour temperature 5,900°K. Exposure index 25 ASA. The following is a summary of the processing sequence:

FERRANIACOLOR REVERSAL PROCESSING PROCEDURE

STEP		REMARKS	TEMP. °F	TIME MIN.	TOTAL MIN. AT END OF STEP
1	First development	Agitate every 15 sec. for the first 2 min., then once a minute	65 ± ½	14	14
2	Wash	In running water	50–65	5	19
3	Reversal exposure	Expose each side of film at 3 ft. from 500W lamp	—	1½	20½
4	Colour development	Same agitation as for first development	65 ± ½	8	28½
5	Wash	In running water	50–65	15	43½
6	Bleach	The film becomes yellow on the emulsion side and blue when viewed through the base	60–65	10	53½
7	Wash	In running water	50–65	5	58½
8	Fix		60–65	8–10	66½–68½
9	Wash	In running water	50–65	15	81½–83½
10	Dry	Dry in a current of clean air after sponging	95		

FILTERS

Filters may be either optically worked coloured glass, dyed gelatin sheet, or dyed gelatin sheet mounted between sheets of white optical glass. They may be used between the light source and the subject or between the subject and the emulsion to change the photographic effect either by correcting or by deliberately producing off-balance results.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Basic filters In colour photography or cinematography a certain number of basic filters are required.

1. An ultra-violet absorbing filter, which may be of special glass or of aesculine-dyed gelatin (e.g. Wratten No. 1A) is advisable to cut out the excess ultra-violet when taking photographs at high altitudes, in snow, in hot countries, or by the sea. It cuts atmospheric haze to some extent and removes the blue cast resulting from excess ultra-violet.
2. An orange filter (Wratten 85, 85B) which enables artificial light film to be used in daylight. By using such filters which cause only a slight loss in speed, artificial light balance film can be used universally. Artificial light films exposed in daylight with an orange correction filter do not show the blue haze frequently found when daylight film is used as the 85 and 85B filters cut out most of the ultra-violet.
3. Bluish filters (Wratten 80 or 80A) on the contrary enable daylight film to be used with tungsten lighting but their use is not generally recommended owing to the large reduction in sensitivity which this method gives. Also the colour balance in some cases is far from perfect.

The table below shows when these filters are used.

	LIGHT SOURCE	DAYLIGHT FILM 5,900°K	TUNGSTEN FILM 3,400°K	TUNGSTEN FILM 3,200°K
DAYLIGHT	Daylight Clear sun	No filter	Wratten 85	Wratten 85B Agfa K19 Gevaert CTO12 Ansco 11
DAYLIGHT	Daylight Overcast sky Bluish light Shaded subject	Wratten 1A Gevaert CTO1 Ansco UV15 Agfa K29G	Wratten 85	Wratten 85B
DAYLIGHT	Daylight Distant views Mountains Aerial photographs	Wratten 1A	Wratten 85	Wratten 85B
TUNGSTEN	Photoflood lamp 3,400°K	Wratten 80A CTB8 + CTB2 Ansco 10	No filter — —	Wratten 81A Ansco UV15 Gevaert CTO1
TUNGSTEN	Blue photoflood lamp	Not recommended as sole light source	Not recommended	
TUNGSTEN	Studio lamps 3,200°K	Wratten 80A + 82A Gevaert CTB12 Ansco 10 Agfa K69	Wratten 82A	No filter
CLEAR FLASH BULBS	Clear flashbulbs PF1, XM1	Not recommended	Wratten 81C	Not recommended
CLEAR FLASH BULBS	PF5, 14, 24, 25, 45, 60, 100 XP, XO, F2, SO, SI	Not recommended	Wratten 81C	Wratten 81EF Gevaert CTO4 Ansco UV17 Agfa K32
CLEAR FLASH BULBS	Blue flashbulbs PF1/B, 24/97, 45/97, 60/97, 100/97, XM1B, SOB, S1B	No filter	Not recommended	

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Besides these essential filters there are many others which should be more widely known and used. In the field of black-and-white photography the use of filters is widespread either for adapting the sensitivity of the film to the type of light used (contrast filters) or to obtain special effects. In colour photography, however, filters are hardly used at all by the amateur although some professionals may make more use of them. There are three types of filter:

1. Correction filters
2. Compensating filters
3. Effect filters

Light correction filters Generally speaking colour emulsions are sold in types designed to give correct rendering in conjunction with particular light sources.

Daylight at 5,900°K

Artificial light Type A for photoflood lamps of 3,400°K

Artificial light Type B for over-run studio lamps of 3,200°K

When the light used is too cold (too blue) or too warm (too orange) for the film in the camera, the lack of balance can be corrected by placing a suitable filter over the camera lens. Most manufacturers supply a series of correction filters for this purpose such as the Wratten series shown below. These gelatin filters can be mounted between parallel pieces of thin glass to increase their robustness. The Wratten 82 series of filters are bluish and increase the colour temperature of the light whereas the 81 series are orange filters and reduce the colour temperature. The steps are fine enough to correct the colour temperature to within about 100°K. These filters should be used together with an accurate colour temperature meter although the table below is reasonably reliable if the colour temperature of the source is known exactly.

Colour compensating filters To change the general colour balance of an emulsion a more complete series of filters can be used known as compensating filters or dilute complementary filters. It is obviously impossible to manufacture films balanced to any type of light likely to be encountered in practice and most manufacturers restrict the range to a daylight type and a material balanced for a specific type of tungsten lighting. Compensating filters are therefore required with all other types of light source but these filters should only be used to correct for relatively small changes in colour temperature and their effect when using a discontinuous spectrum cannot be forecast exactly.

Published recommendations on the choice of filters necessary for any given combination of film and light source are based upon the results obtained photographing a colour chart with all conditions other than the light source being kept constant. Some account should be taken of the differences in colour rendering which may be produced as a result of reciprocity failure. For

LIGHT BALANCING FILTERS

COLOUR OF FILTER	WRATTEN FILTER NUMBER	EXTRA EXPOSURE REQUIRED (STOPS)*	COLOUR TEMPERATURE OF LIGHT SOURCE	
			3,200°K	3,400°K
Bluish	82C + 82C	1⅔	2,490°K	2,610°K
	82C + 82B	1⅔	2,570°K	2,700°K
	82C + 82A	1	2,650°K	2,780°K
	82C + 82	1	2,720°K	2,870°K
	82C	⅔	2,800°K	2,950°K
	82B	⅔	2,900°K	3,060°K
	82A	⅓	3,000°K	3,180°K
	82	⅓	3,100°K	3,290°K
No filter necessary			3,200°K	3,400°K
Orange	81	⅓	3,300°K	3,510°K
	81A	⅓	3,400°K	3,630°K
	81B	⅓	3,500°K	3,740°K
	81C	⅓	3,600°K	3,850°K
	81D	⅔	3,700°K	3,970°K
	81EF	⅔	3,800°K	4,080°K

*These figures are given for guidance only. For accurate work individual calibration must be made.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

example, if two photographs are taken of the same subject made on the same film and lit with the same quality light but of different intensity, such that the required exposures are 0·02 and 2 sec., the results will differ. Differences of this magnitude are particularly noticeable when photographs are taken with tungsten light and flashbulbs despite the two sources being balanced up for colour temperature. The recommended filters, therefore, do not only take into consideration the correction of colour temperature but also the effect of reciprocity failure on the film. (See Reciprocity.)

In cases where the light is very different from that emitted by a black body radiator (see Light) it is impossible to achieve perfect compensation as the source has no colour temperature in the strict meaning of the word. It is however possible to balance up the three emulsions as far as practical work is concerned.

These filters can be used alone or in any combination and any desired correction can be obtained. Such corrections are often necessary when using an unfamiliar light source, or when a heat absorbing glass or an opal glass is used in the light beam. As the use of several filters on either camera or enlarger may result in a loss of definition it is always advisable to use the minimum number of filters to obtain the required correction.

Kodak filters are identified by their density (in hundredths), the letters CC indicating colour compensation, and a letter indicating the colour:

Y = yellow
M = magenta
C = cyan
R = red
G = green
B = blue

For example, CC.20Y specifies a filter:
CC = colour compensating
20 = density 0·20
Y = yellow

Effect filters In some cases the light balancing filters and compensating filters can be used to over-correct the result and therefore behave as effect filters. They can also be used deliberately to falsify normal colour rendering; for example to accentuate strongly the reddish colour of a sunset. Two other special filters should be mentioned in connection with effect filters. These are didymium glass and polaroid filters. The didymium glass filter is a pale purplish (almost neutral) filter which absorbs strongly in the ultra-violet and also in the yellow (particularly the sodium lines). It produces considerable colour distortion and should be used with great care but it can give very pleasing results by increasing the brightness and sharpness of distant photographs.

Polarizing filters (see Polarization) are primarily of use in removing reflections. Some specimens are slightly coloured and often result in a somewhat unpleasant yellowish-green cast with photographs taken in the middle of the day; they have,

KODAK COLOUR COMPENSATING FILTERS

MAX. DENSITY	YELLOW (Y) (absorbs blue)	EXTRA EXPOSURE REQUIRED (STOPS)*	MAGENTA (M) (absorbs green)	EXTRA EXPOSURE REQUIRED (STOPS)*	CYAN (C) (absorbs red)	EXTRA EXPOSURE REQUIRED (STOPS)*
0·05	CC.05Y	—	CC.05M	⅓	CC.05C	⅓
0·10	CC.10Y	⅓	CC.10M	⅓	CC.10C	⅓
0·20	CC.20Y	⅓	CC.20M	⅓	CC.20C	⅓
0·30	CC.30Y	⅓	CC.30M	⅔	CC.30C	⅔
0·40	CC.40Y	⅓	CC.40M	⅔	CC.40C	⅔
0·50	CC.50Y	⅔	CC.50M	⅔	CC.50C	1

MAX. DENSITY	RED (R) (absorbs blue and green)	EXTRA EXPOSURE REQUIRED (STOPS)*	GREEN (G) (absorbs blue and red)	EXTRA EXPOSURE REQUIRED (STOPS)*	BLUE (B) (absorbs red and green)	EXTRA EXPOSURE REQUIRED (STOPS)*
0·05	CC.05R	⅓	CC.05G	⅓	CC.05B	⅓
0·10	CC.10R	⅓	CC.10G	⅓	CC.10B	⅓
0·20	CC.20R	⅓	CC.20G	⅓	CC.20B	⅔
0·30	CC.30R	⅔	CC.30G	⅔	CC.30B	⅔
0·40	CC.40R	⅔	CC.40G	⅔	CC.40B	1
0·50	CC.50R	1	CC.50G	1	CC.50B	1⅓

*These figures are given for guidance only. For accurate work individual calibration should be made.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

FILTERS FOR COLOUR FILMS

Light Sources	C.T. ° K	Anscocolor - Anscochrome						Agfacolor			
		D 5,900°		F 3,800°		T 3,200°		T 5,500°		K 3,200°	
	10,800										
	9,000							K 33	1		
	8,500	UV 17	1/4								
	8,000										
	7,500							K 33 A	1		
	7,300	UV 16	0			12	0				
	7,000										
	6,800										
	6,500	UV 15	0					K 29 G	1/3		
Electronic flash	6,250										
Blue flashbulbs	6,000										
Daylight	**5,900**	None				11	0			K 19	
	5,700										
	5,500							None		K	
	5,400										
	5,000										
	4,600										
	4,100										
Flash PF 1.....	**4,000**							K 28	1/3		
	3,900										
Flash PF 14.....	**3,800**	10 + UV 17	2			UV 17	0			K 32	
	3,700										
	3,600	10 + UV 16	2			UV 16	0			K 31	
	3,500					13	2				
Photoflood lamp	**3,400**	10 + UV 15	2	82 A	1/3	UV 15	0				
	3,300										
	3,290										
Studio lamps...	**3,200**	10	2			None		K 69	2	None	
	3,100										
Tungsten	3,000										
500 W.....	2,900	10	2								
250 W.....	2,800										

The figures given after the filters represent the amount

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

AND DIFFERENT LIGHT SOURCES

Light Sources	C.T. °K	Kodachrome - Ektachrome						Gevacolor			
		D 5,900°		F 3,800°		B 3,200°		R5-N5 5,900°		R 3 3,200°	
	10,800	81 EF	2/3							CTO 20	3/4
	9,000	81 D	2/3								
	8,500							CTO 4	1/4		
	8,000	81 C	1/3								
	7,500							CTO 2	0		
	7,300	81 B	1/3								
	7,000									CTO 16	3/4
	6,800	81 A	1/3								
	6,500							CTO 1	0		
Electronic flash	6,250	1 A	0								
Blue flashbulbs	6,000										
Daylight	**5,900**	None		85 C	2/3	85 B	2/3	None			
	5,700									CTO 12	1/2
	5,500										
	5,400							CTB 1	1/4		
	5,000							CTB 2	1/2		
	4,600							CTB 4	1	CTO 8	1/3
	4,100										
Flash PF 1.....	**4,000**										
	3,900										
Flash PF 14.....	**3,800**			None		81 EF	2/3	CTB 8	11/2	CTO 4	1/4
	3,700					81 D	2/3				
	3,600					81 C	1/3			CTO 2	0
	3,500					81 B	1/3				
Photoflood lamp	**3,400**	80 A		82 A	1/3	81 A	1/3	CTB 8 + CTB 2	2	CTO 1	0
	3,300					81	1/3				
	3,290							CTB 12	21/4		
Studio lamps...	**3,200**	80+82 A	21/3	82 C	2/3	None		×		None	
	3,100					82	1/3				
Tungsten	3,000					82 A	1/3			CTB 1	0
500 W.....	2,900					82 B	2/3	CTB 16	3	CTB 2	0
250 W.....	2,800					82 C	2/3				

in stops by which the lens aperture must be increased.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

however, little effect on photographs taken early in the morning or late in the evening. By using a pale magenta filter this cast can be corrected. These filters deserve to be more widely used as they have the following effects:

1. Clarifying distant views by the reduction of atmospheric haze.
2. Reduction of reflections, particularly from water, glassware, varnished pictures, and other non-metallic surfaces.
3. Deepening the sky colour and darkening the surface of the sea and rivers.

Familiarity with their effects opens up a considerable field of special effects in colour photography.

Use of filters for projection The overall balance, and particularly the highlights, can be corrected by the use of filters during projection. When a long series of transparencies which are too warm or too cold are projected, the correction filter may be fitted over the projection lens. It is much more common, however, that individual transparencies will require correction to bring them into line with others in a group and this is done by mounting the filter with the transparency, preferably between glass. Coloured cellophane often gives the required correction and is much cheaper than dyed gelatin.

Use of filters in printing Colour filters are most widely used when making colour prints or duplicates. Unwanted colour casts in transparencies can be corrected during printing with colour correcting or compensating filters. The colour of the printing light can also be changed and the print stock is brought into line in this way. When printing from transparencies the filter required is the complementary of the cast, i.e. a magenta filter is used to correct a green cast.

The use of 'universal' negative materials which are used unfiltered in daylight or artificial light makes the use of correction filters essential. In this application the filter used is of the same colour as the cast, i.e. a blue filter removes a blue cast. (See Negative-Positive printing.)

Handling of filters The filters used in colour photography may be of gelatin sheet, or gelatin mounted between glass. For large filters (above 42 mm. diameter), the sheet filters can be used instead of mounted ones if desired and a special filter holder is used for them. Smaller filters are more readily available cemented between glass and in filter holders to fit the lens.

Although gelatin filters are protected by a thin layer of collodion they are very fragile and must always be handled by the edges to avoid fingermarks. To cut them they should be placed between two sheets of paper and they should always be kept covered, as dirt and dust are virtually impossible to remove. For temporary use the filters can be cut into a disc which is placed in the usual type of filter holder or may be fixed over the front of the lens with adhesive tape. For regular use, however, mounted filters are preferable. Mounted filters should be cleaned with as much care as is taken in cleaning a lens. Dust should first be removed with a very soft brush and then the surface is cleaned with soft cotton material or with lens tissue. Breathing on the filter often helps to remove persistent marks.

FLEXICHROME PROCESS

This process is not actually a colour photographic process. It enables colour prints to be made from original black-and-white and colour negatives by the application of water soluble dyes to a gelatin relief image. It is included in this book because of the high quality of the *coloured* photographs which it gives. Its principal point is that, as opposed to other colouring processes, the original black-and-white image can be removed completely. Furthermore, the use of a gelatin relief simplifies colouring and gives sharp boundaries to the coloured areas.

Principle of the process An ordinary black-and-white negative is printed by contact or enlargement on to a Kodak Flexichrome film. This is then processed in a similar way to the Matrix film used in Dye Transfer (q.v.). After hot water developing a gelatin relief image is obtained which, after bleaching the silver, is treated with a black dye known as the modelling agent. At this stage the image has the appearance of an ordinary black-and-white print. The thin film carrying the black image is then separated from the original support and is transferred relief uppermost on to a final white paper support.

The Kodak Flexichrome dyes are then applied locally with a brush and are absorbed by the image in proportion to the thickness of the gelatin relief. The excess dye is removed by blotting. The colouring of the print is semi-automatic for on one hand the gelatin only accepts dye in proportion to its thickness and on the other hand the colour is deepened to a greater or less extent by the modelling agent according to the brightness of the subject. The dye which is applied gradually removes and replaces the black modelling agent contained in the layer. The colour therefore appears in the light and medium areas before the shadows and in the extreme highlights and white areas there is only a very thin layer of gelatin which takes up

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

very little dye. The final print has a range from black to white including any colours and subtle mixtures which are required.

Note The Flexichrome process has the advantage of enabling colouring to take place in as many stages as are necessary. The dyes are fixed in the gelatin relief by treatment in acetic acid solution yet can be removed at will and replaced by others using a suitable solution. This process is primarily used for high quality advertisements and for photogravure originals. In the latter case it is used to produce colour prints from black-and-white negatives and the quality can approach that of a three-colour print with the advantage of a choice of colours not found in the original.

FLOWER PHOTOGRAPHY

Flower photography is one of the principal spheres of colour photography owing to the unsatisfactory nature of black-and-white flower photographs. Nevertheless this attractive subject is one of the most difficult. It requires very good taste and considerable experience on the part of the photographer to avoid commonplace rendering and achieve the delicate results which are required. Photographs taken of large masses of flowers in gardens are rarely satisfactory. A hotchpotch of small unrelated coloured areas never gives the correct impression. The lack of a dominant point of interest due to the mass of small areas and the difficulty in calculating the correct exposure for a wide range of objects loses all the subtlety of colouring. The predominant green foliage influences the whole picture and gives excessive contrast with the other colours.

Open air work The first point which must be watched is the very small depth of field which is available when working close to the subject. Stopping down increases the depth of field but at the same time requires a lower shutter speed and increases the loss of sharpness due to movement. In most lighting conditions depth of field is chosen so that the particular flower stands out from the background. The lack of sharpness of the background accentuates the flower itself but large coloured areas in the background should be avoided. If the flower is close to other background objects, working at a very large aperture to lose the background is inadvisable owing to the sudden fall-off in sharpness. It is far better to change the viewpoint so that the background is less conspicuous. If this cannot be done it is better to cover the background areas with a sheet of neutral coloured paper placed at a reasonable distance behind the flower. As the contrast of flowers may be very high even with frontal lighting, the use of white paper reflectors outside the field of view is strongly recommended as with other outdoor subjects. The shadows are then brightened and coloured reflections from other nearby flowers are reduced. The effectiveness of a reflector is very great as the small distance between the reflector and the subject allows the maximum amount of light to be directed into the shadows. Even side- or back-lighting can give good results with only a reflector to light the shadows.

As correct colour rendering is one of the foremost requirements it is essential to work in the middle of the day and if the subject is in shadow and lit only by sky light or by reflection from the clouds, information on the use of correction filters based on previous work is essential — in particular filters to cut down the predominance of blue.

As many flowers are to some extent fluorescent, ultra-violet radiation does not cause a general excess of blue but rather an increase in brilliance — the bluishness only appearing in other parts of the image.

Tungsten balance film can obviously be used together with the appropriate correction filter and this filter will to a large extent cut down ultra-violet and give slightly warmer results than would be obtained using daylight film.

Indoor work When working with daylight indoors it is absolutely essential to reduce the lighting contrast with reflectors. The use of artificial light fill-in is usually unsatisfactory as it does not exactly match the daylight and the subtle colourings are lost. The possibility of putting the flowers in a vase and selecting the most suitable background simplifies the production of good colour photographs and this is especially so when artificial lighting is used.

It may be thought that the small area of the subject enables low powered lighting to be used at fairly close distances, but this is not so. For one reason, shadows produced by nearby lamps are very pronounced. Secondly, the heat of the lamp close to the subject may cause the petals and foliage to move slightly; even though this may not be noticeable, it may be enough to produce unsharp pictures if fairly long exposure times are used. It is much better to have the lamps further away lighting a large area, for even with more powerful lamps the effect of heat has been shown to be far less and longer exposures can be used.

Generally the most satisfactory lighting equipment comprises a number of floodlamps in a large diffusing reflector to give a general illumination together with a spotlamp to give the required modelling.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

The calculation of exposure must be carried out with great accuracy and must always be based on the highlights to avoid over-exposure; pale flowers become washed out in colour with even slight over-exposure but are still acceptable with slight under-exposure. Flash is rarely used indoors — it is only necessary in certain cases such as taking photographs at an exhibition. Outdoors when high shutter speeds must be used to stop movement, on a windy day for example, electronic flash is useful.

Certain blue flowers, such as Morning Glory, often appear rather reddish when lit with sunlight. Bluer results can be obtained by choosing blue sky light as the main illumination.

FLUORESCENCE

PHOTOGRAPHY OF FLUORESCENT OBJECTS BY ULTRA-VIOLET

The invisible ultra-violet radiations close to the visible region (around 3,600Å) are particularly suitable for the excitation of fluorescent materials. Fluorescence can be readily photographed in colour.

Production of the ultra-violet radiation Mercury vapour lamps — and especially high pressure lamps — are very suitable as ultra-violet sources. Special types of fluorescent lamp can also be used in which the fluorescent layer of the tube is replaced by a coating which absorbs rather than radiates visible light. In both cases the emission should be filtered so that only the most useful radiations pass through. To do this a special nickel oxide glass is used which was perfected by the American physicist Wood, hence the name 'Wood's Light' for the active ultra-violet rays. When these radiations are received by certain compounds visible light is emitted. This phenomenon is termed fluorescence when the light ceases when excitation ceases, or phosphorescence when the visible light continues after excitation ceases. The persistence of the light in phosphorescence varies with different phosphorescent substances. A large number of compounds — salts, varnish, cloth, plastics, liquids, powders, etc — are or can be made phosphorescent or fluorescent and together with an ultra-violet source present a wide field of possible uses.

Among the principal applications are:

1. In industry — fluorescent analysis, control of manufacture, etc.
2. Fluorography — this consists in treating the object to be examined with a fluorescent compound which is concentrated in cracks and crevices. In this way it is possible to photograph the surface condition and show very fine irregularities.
3. Examination of documents, works of art, precious stones, sculpture, postage stamps, bank notes, etc.
4. Décor — in theatres, ballets, cabarets, circuses, etc, where the whole visual effect is changed as the ultra-violet radiation is switched on to illuminate the set giving a complete change in appearance with no apparent change in the set.
5. Posters, hoardings, etc — these show up more vividly when fluorescent paints and inks are used, especially when they are irradiated with ultra-violet in the dark.

These phenomena can be photographed in two ways:

1. By placing an ultra-violet absorbing filter over the lens so that only the visible re-emission is seen.
2. By placing a filter of Wood's glass over the lens; this cuts out the visible emission and only records the ultra-violet.

In fact it is only the first of these which is of interest in colour photography and although there is no difficulty in principle involved in photographing fluorescent documents, etc, there are several problems involved — the excitation, choice of emulsion and filters, and the exposure.

Excitation Frequently the photographer will find that the subject is already irradiated with ultra-violet and he must adapt his technique to the prevailing conditions. If the subject is a suitable one to be photographed it is generally found that the irradiation system is satisfactory. In other cases the photographer must make his own arrangements for excitation and he must therefore equip himself with high pressure mercury vapour lamps in nickel oxide glass envelopes.

These lamps are often used in conjunction with an additional Wood's glass filter, particularly in photomicrography. In this latter case the radiation can be concentrated on to the sample by means of a thin glass spherical flask filled with carbon tetrachloride.

It is, however, simpler to use an ordinary condenser of the type used in enlargers as the glass despite its thickness absorbs only a small part of the near ultra-violet. It is often better to use direct rather than transmitted illumination.

The lamps are arranged so that the greatest brilliance of fluorescence is obtained. The inverse square law on distance does not alter these conditions. For very luminescent samples (lacquers, plastics, materials and even certain minerals) the result is almost the same if the lamps are at a

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

distance of 1 ft. or 3 ft. On the other hand, for samples of low luminescence such as documents, the lamps must be brought as close as possible to obtain strong excitation. For such documents, two 'Mazda Maw 75' lamps at 8 in. should be suitable.

Sensitive materials All types of colour film can be used and there are no special requirements about cameras. The Leica, Contax, and other precision miniatures are widely used because of their large range of accessories developed for special purpose photography.

It is best to use daylight balance film as the reproduction should show the normal visual effect.

In certain cases it may be preferable to use artificial light film with the appropriate daylight correction filter as in this way the abundant ultra-violet radiation is cut out. The sensitivity of this combination of tungsten film and correction filter may be greater than that of daylight film with an aesculine ultra-violet absorbing filter. It is also more convenient to use tungsten balance film as the majority of laboratory work calls for this stock, so no change to a different type in the middle of a roll is necessary.

Filters When using ordinary daylight stock the film must only receive the visible radiation from the fluorescent compounds.

The ultra-violet which is reflected unchanged from the sample must not be allowed to reach the film, nor must the ultra-violet fluorescence which always accompanies visible fluorescence. The ultra-violet will primarily affect the blue sensitive emulsion; the emulsions behind the integral yellow filter layer will be largely protected and therefore the photograph will have a bluish cast. It is also possible that the gelatin used in the emulsion will have a bluish fluorescence. A filter which completely absorbs the ultra-violet but no visible light must therefore be used; any absorption of visible light will bring about a colour cast.

The commercial filters are not generally suitable as they do not completely absorb the ultra-violet or are distinctly yellow in colour. It is often necessary to use liquid filters which are not easy to make or use outside a laboratory but which give by far the best results. One of the best liquid filters is sodium nitrite solution which has the advantage over many other filters in that it is not itself fluorescent. It is used as a 5 per cent solution with a thickness of 8–10 mm. The solution should be boiled for some time before introducing it into the filter cell in order to remove dissolved gas and avoid the formation of air bubbles in the filter when it becomes warm in use. When the exciting radiation is accompanied by a small amount of visible violet light due to the Wood's glass filter being too thin its effect is nullified by adding a little potassium dichromate to the sodium nitrite solution; the quantity necessary is determined as follows:

A piece of clean aluminium is illuminated by the ultra-violet source and examined through the sodium nitrite filter. The aluminium is not fluorescent and if it appears slightly violet a strong solution of potassium dichromate is added drop by drop to the solution in the cell until the violet coloration disappears. The solution should be agitated after each addition of dichromate.

Another method disclosed by Peterson is to use two Wratten 2B filters for Kodachrome and a CC. 10R and CC. 10G together for Ektachrome.

Good results have also been obtained for practical work using a Wratten Aesculine filter together with a pale yellow or by using a dydimium filter.

General technique If the photographer uses his own exciting lamps they should be allowed to warm up for some time to reach their maximum intensity. A period of 10 min. is usually sufficient. For determining the exposure with an ordinary photo-electric meter, the cell should be covered by the same filters as those used over the camera lens. Another method is to turn out the room lights, and when the eyes have become adapted to the darkness, close the lens iris as far as possible and, observing the image on the ground glass screen, gradually open the diaphragm until an image is just seen. If the image becomes visible at $f/32$, the exposure will be about 15 min. at $f/16$; if it is not visible until $f/8$ is reached the required exposure will be about four hours at $f/16$. These figures assume the use of a 10 ASA colour film. The exposure will have a considerable effect on the result as colour films do not have the same exposure latitude as panchromatic materials. The exposure will obviously vary according to the brilliance of the subject and several tests are sometimes necessary to obtain the best results.

The following examples give some idea of the order of the exposures which are necessary. They refer to correctly exposed transparencies made on Kodachrome film (10 ASA to daylight).

In photomicrography a Spencer microscope was used with enlargement from 30 to 100 diameters. The light was obtained from a 'Maw 75' lamp with an additional Wood's glass filter and a condenser. Exposure times were from 1–6 hours according to the subject. (2 hours for diamond chips.)

For photomicrography two 'Maw 75' lamps were used 8 to 12 in. from the subject. Exposure times with the objective wide open at $f/8$ and with a sodium nitrite-potassium dichromate filter were:

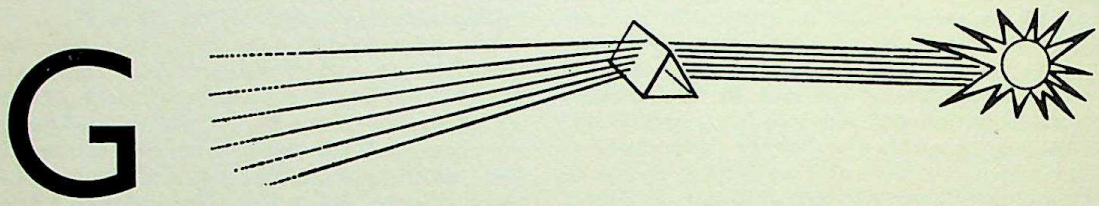
Very luminescent minerals Paintings Plastics	1–5 min.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Moderately luminescent minerals (fluorite, willenite), Paper, Ivory	10–20 min.
Slightly fluorescent minerals (calcite)	20–30 min.
Documents, Stamps, Fossils	30–120 min.

Theatrical décor, posters, decorations, etc, require longer exposures mainly due to their size and consequently greater distance of the lamps. To cover an area 3 × 6 ft. using two lamps at 12 ft. and two lamps at 6 ft., the exposure necessary is 10–30 min. at *f*/8. With a wide aperture lens and very luminescent objects, exposures from 5–30 sec. at *f*/2·8 can be reached but fractional exposures are still almost impossible. A tripod is therefore always necessary. Tests have recently been made using electronic flash with 1,000 joule lamps over which a relatively thin ultra-violet transmitting cover is fitted.

With a certain amount of practice and following the general rules given above colour photographs of fluorescent phenomena can easily be taken by the amateur.



GASPARCOLOR PROCESS

Outline This process, which has been developed by Bela Gaspar, depends on the property of finely divided silver to behave as a catalyst in redox reactions involving dyes. In other words, Gasparcolor belongs to the group of processes in which a dye present in a photographic layer is destroyed in the presence of silver by a suitable reducing solution giving a positive from a negative silver image.

This type of process was originally patented by Christensen who described dyes which were not affected by strong reducers such as hydrosulphite or stannous chloride in the absence of finely divided silver but which were destroyed catalytically in the presence of a silver image.

Gaspar patented a process in which the dyes are reduced in acid solution by the silver, the latter being oxidized to a silver ion. The reaction is only possible if the solution contains a silver ion acceptor such as an alkali bromide or thiourea which precipitates or forms a complex with the silver ion. The reaction is catalyzed by phenazine derivatives such as 2:3-dihydroxyphenazine.

The simplified theory of the process is as follows: a silver ion is produced from a silver metal image and an acid solution; during this reaction nascent hydrogen is formed. The reaction proceeds in this direction as long as a silver ion acceptor (thiourea) and a nascent hydrogen acceptor (a dyestuff which is relatively easily reduced to a leuco derivative) are present. The presence of a substance which is easily reduced to the leuco state (phenazine derivative), in the presence of thiourea in particular, accelerates the proceeding reaction, behaving as an intermediate between the nascent hydrogen and the dye which is to be reduced.

Ag metal + hydrochloric acid →
Ag ion + nascent hydrogen
Ag ion + thiourea → stable complex
Nascent hydrogen + dye → leuco derivative

The dyes which are most suitable for this type of process are obviously those which form a leuco derivative that is readily removed from the emulsion layer. The azo dyes have always been the most important as the dyes themselves are stable and are available in a wide range of hues.

Gasparcolor procedure In the first version of the Gasparcolor process, the three black-and-white images were printed from three positives obtained from separation negatives. These were obtained by successive exposure in a cine camera and the presence of time parallax was a consider-

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

able handicap.

The Gasparcolor positive film comprised two emulsion layers sensitized respectively to blue and green on one side of the film and a third layer sensitive to blue was coated on the other side. The first two layers contained the yellow and magenta dyes and the cyan dye was in the third layer. The printing from the three separation positives was carried out in a special printer in two stages (page 37).

In the first stage the outer blue sensitive layer (yellow dye) was exposed to blue light through the blue filter positive. At the same time the layer on the opposite side, also blue sensitive (cyan dye), was exposed by blue light through the red filter positive. In the second stage the colour sensitized layer (magenta dye) was exposed by yellow light through the green filter positive.

The three corresponding negative silver images were simultaneously developed and after bleaching the final positive colour image was obtained.

In a later version which was marketed in the USA the positives were printed from a colour transparency. The transparent base was replaced by opaque white plastic and the three layers were coated on the same side giving a material suitable for making 'paper' prints. The exposure consists of a single step either by contact or enlargement using the same method of colour balancing with filters as is used for Ansco Printon.

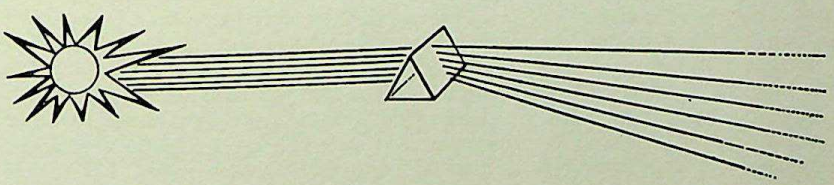
The processing procedure is: black-and-white development, rinse, fix, rinse, dye reduction, wash, bleaching of the silver image, fix, final wash, dry.

GEVACOLOR (Reversal film)

Gevacolor reversal film, R5, is a conventional subtractive tripack material with the couplers present in the emulsion. It is available in two versions: (1) 35 mm. and rollfilm, rated at 40 ASA for making direct transparencies with daylight; (2) cine film for 16 mm. and double-track 8 mm. cameras rated at 10 ASA to daylight. The CTO and CTB, colour correction filters are designed to correct any change in light source.

GEVACOLOR (Negative-positive film)

Gevacolor negative film, N5, has the same structure as Gevacolor reversal film. It is balanced for use with daylight and has an exposure index rating of 25 ASA.



H

HISTORY OF COLOUR

An enormous number of inventors directed their efforts towards colour reproduction without unduly concerning themselves with the problems of black-and-white photography; only in the field of perpetual motion have a greater number of fallacious and stupid solutions to the problem been proposed. Colour photography has the advantage of not being basically impossible, but in the large range of promising inventions many have been shown to have no practical value.

Becquerel 1848 The first colour images were probably obtained by Edmond Becquerel. This physicist was the second of the famous family of four who succeeded to the chair of Physics at the Museum and at the Académie des Sciences. Becquerel projected a solar spectrum on to a plate coated with silver chloride containing free silver and after a long exposure a reflected reproduction of the colours of the spectrum was seen. He was not successful in fixing this image so the plate had to be kept in the dark and could only be examined for brief periods. (Some examples still exist.) The mechanism of this reproduction was probably an

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

interference phenomenon similar to that which Lippmann perfected some forty years later.

Maxwell 1859 Whilst the discovery of Becquerel was a chance one and not followed by any practical application, the work of the Scottish physicist Maxwell formed the basis for much subsequent work and in 1859 Maxwell projected the first colour photographs. Maxwell's ideas were based upon work carried out by Thomas Young who first put forward the wave theory of light. In 1801 Young wrote, 'as it is almost impossible to conceive that each sensitive point of the retina contains an infinite number of particles, each capable of vibrating in unison with a given light wave, it must be assumed that this number is limited for example to three principal colours, red, yellow and blue'. This was the first enunciation of the three colour theory of vision (see Colour Vision), but subtractive three colour synthesis was already known. In 1722, for example, the engraver Le Blon had made colour prints using seven plates (from the seven spectral colours according to Newton) and eventually stated that three would be sufficient, coloured respectively red, yellow and blue. It is undoubtedly on this basis that Young chose his 'principal colours' which we now call the primaries, but he mixed up additive subtractive synthesis and it was not until 1807 after Wollaston's work on the solar spectrum that he replaced his previous choice with red, green and blue-violet. This hypothesis of Young remained dormant until 1852 when it was taken up and developed by the German physicist and physiologist, Helmholtz. It was to prove the conceptions of Helmholtz that Maxwell, in 1857, constructed his 'colour box', a type of spectrograph with which he was able to make the first colour triangle, the ancestor of modern colorimetry. Maxwell was able to show that all colours except the most saturated ones can be reproduced by adding together the three primaries in suitable proportions. In 1859 Maxwell gave a photographic demonstration of this principle by projecting in register on to a screen images coloured respectively red, green and blue.

Whilst the principle of this additive synthesis was correct, Maxwell had great difficulty firstly with his triple projection system and the difficulty of registration and secondly because at that time the sensitivity of photographic emulsions to green was very low and to red practically nil. The exposures to red and green were therefore very great.

Cros & Ducos du Hauron Without knowing of the experiments of Maxwell, the French poet Charles Cros deposited a *pli cacheté* with the Académie des Sciences in 1867 in which he put forward the principle of additive trichromatic synthesis. The same idea was put forward by Ducos du Hauron who in 1869 independently published a description of several methods of colour photography by additive and subtractive trichromatic synthesis. Unfortunately these ideas were far in advance of the technical developments and it was not until many decades later that their ideas could be put into practice.

Lippmann 1891 In 1891, Gabriel Lippmann obtained colour photographs using an ingenious interference system. A 'grainless' emulsion was placed in a dark slide, glass towards the light and with a mirror consisting of a bath of mercury on the emulsion side. Stationary waves were produced in the emulsion by interference of the incident and reflected light and after the plate was developed and fixed these waves produced layers of silver in the emulsion, the layers corresponding to the wavelength of the incident light. By placing his plate again on to a bath of mercury and viewing by reflected light the original colours were reproduced. Lippmann took some excellent photographs, some of which are kept at the Sorbonne but the insensitivity of his plates and the complication of the mercury mirror ruled out any commercial application. It should be noted that the Lippmann process reproduces perfectly the physical structure of the light without recourse to the simplification resulting from the theory of three colour synthesis. The same remarks apply to a process invented in 1895 by Lanchester. An image of the subject is formed on a grid whose transparent areas are much finer than the opaque part separating them. Each transparent band behaves as a spectrograph slit and by means of an acute angle prism and lenses produces a small spectrum on the emulsion corresponding to the colour of the light received. A transparent print of the negative is then registered with the same grid and optical system, and an excellent colour picture is obtained by projection. The complications of the process and the difficulty of exact registration are obviously insuperable obstacles to such a method.

Lumière 1907 None of the above experiments led to a practical process but one of the methods disclosed by Du Hauron was to produce an additive trichromatic synthesis by means of adjacent filters on the same plate. The first method (Joly 1893) used parallel coloured bands 0·1 mm. wide but this screen was too coarse. In 1907 the Lumière brothers produced their Autochrome plate which was the first satisfactory process. Their coloured filters consisted of a mixture of red, green and blue-violet dyed starch grains 0·01 to 0·02 mm. in diameter, dispersed at random over the surface of the plate. The results were quite good but the sensitivity of the plates was low and the resulting photographs were very dark for even in the high-

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

lights 90 per cent of the light was absorbed by the dyed grains or the opaque matrix in which they were dispersed (see under Additive Processes).

Additive motion picture processes The advent of cinematography brought about a return to the additive synthesis demonstrated by Maxwell in 1859 and perfected by another pioneer, F. E. Ives, in 1889. The simplest method was the successive projection of red, green and blue images and to avoid flutter it was necessary to triple the projection speed and consequently the length of the film. Furthermore colour fringes were present on moving objects and to avoid these it was necessary to project the three images simultaneously.

One method was to use very wide film (Gaumont 1909) but exact registration was extremely difficult and very high powered projectors had to be used. In the more recent Rouxcolor the individual images were of small size and register was assured by using a special optical system. The necessity for very powerful arcs still remained and this process also suffered from poor definition due to the small size of the individual images.

Another additive method for cinematography was proposed by Berthon in 1908 and developed by Keller-Dorian in 1923. The film is exposed through the base which is embossed with microscopic lenticular elements (page 35), each of which produces an image of the lens on the emulsion. A coloured filter consisting of three bands (red, green and blue) is placed over the lens and produces on the emulsion a mosaic (or a series of parallel lines if the embossed lenses are cylindrical) similar to that of Lumière's Autochrome. During projection the procedure is reversed and a colour image is produced on the screen. The difficulty of printing these films limited the process to substandard amateur films (Kodacolor and Agfacolor about 1928).

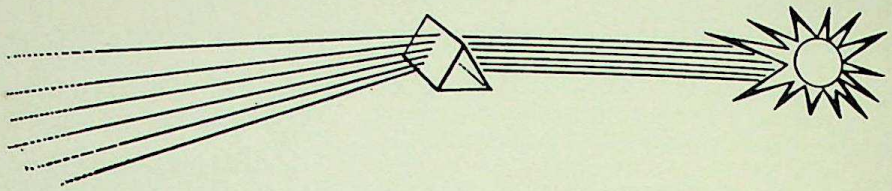
Subtractive processes In these processes the colours are obtained by mixing or superimposing dyed images. Charles Cros (1881) suggested the use of fugitive dyes which were partially decolorized. These colour sensitive layers were made by Vallot (1895) and by others and were even used commercially (Smith's Utocolour Paper 1904) but very great exposures were necessary and the colours were far from satisfactory and were unstable.

A much better method was disclosed by Du Hauron (1897). This consisted of superimposing three silver bromide emulsions which were subsequently coloured. The first processes used separate superimposed films but the modern methods are based upon the disclosures of Schintzel (1905) and Fischer (1912). The film is coated with three superimposed layers in each of which a coloured image is produced by the colour development process without the necessity of separating the layers. Such a process was perfected by Mannes and Godowsky between 1930 and 1935 and was the basis of commercial processes for amateur photography (Kodachrome 1935).

A much simpler type of process was widely used for motion picture work employing a positive film coated on both sides. The film was printed from separation negatives, the long wavelength negative on the one side and the short wavelength negative on the other. After toning the resulting images cyan and red-orange a two-colour film was obtained giving inaccurate though quite pleasing results (Thornton 1912).

Conclusions This brief historical survey of colour cinematography follows the customary division into additive and subtractive processes. In one case images of several different colours are mixed together on their projection screen or on the observer's retina and in the other the light passes through a number of coloured layers. Another general classification depends on a third factor — where the colour is recorded. As an ordinary emulsion can only record variations in light and therefore of form, this third factor is either time (successive projection), the multiplicity of pictures (Maxwell's synthesis) or, in more common use, where a single film is used by the juxtaposition of coloured images (Lumière, Berthon) or their presence in different strata (Lippmann, Fischer). It should not be assumed, however, that the final stage has been reached. Developments are constantly taking place in this field and it is quite possible that an entirely new type of process may be developed.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



ILFACHROME (Reversal colour film)

A colour film manufactured by Ilford yielding positive colour transparencies by a reversal process. It is suitable for exposure with daylight, blue-coated flashbulbs, and electronic flash without a filter, though with electronic flash an Ilford Q, No. 805 filter or ultra-violet filter may be needed. It may also be used with Photoflood lamps with an Ilford No. 351 filter, though its effective exposure index is then only 2·5 ASA.

Ilfachrome, daylight type, 10 ASA.

Processing, etc The film must be returned to the makers for processing in the bag supplied, and the price of the film includes processing and mounting in card mounts. On request the film will be returned uncut. Ilford Colour Prints, duplicate transparencies and black-and-white negatives may also be obtained.

ILFACOLOR (Negative colour film)

A colour film manufactured by Ilford to yield masked colour negatives for printing on Ilfacolor paper to give colour prints. It can be exposed with daylight, electronic flash, clear flashbulbs and tungsten lamps of 3,400°K and 3,200°K without the use of a filter over the camera lens, unless it is desired to produce negatives of uniform colour balance.

Ilfacolor Roll Film,
exposed with daylight, 32 ASA.
exposed with Photoflood, 20 ASA.

Lighting contrast Since the contrasts of Ilfacolor Negative and Paper cannot be adjusted in processing, it is necessary to keep some control over lighting contrast. In general, it should be possible to produce good 'straight' prints if the lighting contrast is no greater than 3:1. In daylight the lighting contrast may be reduced by illuminating the shadows with a blue-coated flashbulb.

Processing All films must be returned to Ilford for processing, and processing kits are not available.

INTERIORS IN COLOUR

Light sources As a light-source, the sun can only be used for a few hours a day, and then only under certain conditions. For indoor work it is usually an unreliable and variable source and it is therefore necessary to use some form of artificial lighting. The features of such lighting are reliability and ease of use as well as the freedom of choice given to the photographer.

A very wide range of artificial light sources is available:

1. For Type B film balanced to a colour temperature of 3,200°K.
   Studio lamps with a life of about 50–100 hours which are usually used for general illumination.
   Projector lamps also with a 50–100 hour life; these are used in spotlamps.
2. For Type A film balanced to a colour temperature of 3,400°K.
   Photoflood lamps with a built-in or an external reflector — average life 2 to 6 hours.
   Flashbulbs with Wratten 81C filter over lens.
3. For Type F film balanced for use with clear flashbulbs of the wire- or foil-filled variety which corresponds to a colour temperature of 3,800°K–4,000°K.
   Clear flashbulbs without filter.
   Photoflood lamps with Wratten 82A filter over lens.
4. For daylight film balanced to a colour temperature of 5,900°K.
   Blue photoflood lamps — life 2 to 6 hours.
   Electronic flash — tube life about 15,000 flashes.
   Fluorescent lamps of the daylight type.
   Flashbulbs with blue coating as main or fill-in light.

Sunlight can play a part in interior lighting; it can also be used as fill-in light in conjunction with other light sources.

Multiflash portrait by Alfons Rudolf using a Retina Reflex camera and Kodachrome film. ▶

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Ordinary domestic lamps can be used in conjunction with films of 2,900°K or with 3,200°K film if a Wratten 82B or 82C filter is used to raise their colour temperature which is normally about 2,850°K.

Emulsions Both daylight and tungsten type films are used for interior work depending on the type of lighting which is available. Tungsten balance film is available in three types — for 2,900°K, 3,200°K and 3,400°K.Tungsten film can be used in daylight with the appropriate orange correction filter, but the reverse procedure is not recommended due to the relatively great loss in effective speed. To determine the colour temperature of unspecified sources, and to keep a constant check on the exposure conditions a *colour temperature meter* (q.v.) is indispensable. It can be used to measure the colour temperature of the source either to determine the choice of film or to determine the choice of filters necessary to balance the film and the light source. Except in cases where a special effect is wanted, lamps or sources of different colour temperature must not be used together.

Equipment Lighting equipment for colour work does not differ greatly from that used for black-and-white except in the control of colour temperature. The camera itself is critical only insofar as its size or format affects the choice of film. The camera lens must be achromatic — that is, the images produced of different colours are all in the same plane. An exposure meter is almost indispensable in the studio as tables do not give the necessary accuracy when several sources have to be considered.

The lighting equipment comprises spotlamps and floodlamps. The spotlamps are used as the principal source and for accentuating particular areas; they have plano-convex or Fresnel lenses which must be of good quality white glass so that the colour of the light is unaltered. The same effect may also apply to the floodlamps whose reflectors must be white or white metal — preferably silver-plated. The distribution of light from these reflectors is often uneven and results in over-exposure in the centre of the field and under-exposure around the edges. Such faults can also be found in reflectors fitted to flash equipment — both bulbs and electronic. Other items of lighting equipment which are of great value are reflector-boards and diffusers, both of which are used to balance the lighting.

Contrast As most colour materials have only a small brightness range, lighting contrast must be carefully controlled. With open lamps the light decreases rapidly as the lamp-to-subject distance increases, obeying the inverse square law; if an exposure of 1 sec. is required with the lamp at a distance of 2 ft., the time will be increase to 4 sec. if the distance is doubled to 4 ft. This does not apply to spotlamps, where a fully-focused beam of nearly parallel rays will show little change over the normal working distances. Their effective illumination is in fact controlled by the focus adjustment on the lamp. The background in subjects like portraits often tends toward under-exposure and it is usually necessary to light the background with additional lamps (see Portraiture).

If colour rendition is particularly important, flat lighting is often advisable. For most work, however, the relationship of highlight and shadow areas is balanced to give a more lively and attractive picture. Highlights can be very brilliant if they only occupy a small area of the picture, and the same applies to deep shadows which can often be used very effectively to accent a rather flat subject. In general the lighting contrast should not exceed 3:1 and for most subjects can be as low as 2:1.

Daylight indoors It is preferable to use daylight type film and to work at a time when the spectral composition of the light is correct. Sometimes a 1A filter is used to reduce the effect of the blue sky; an overcast sky provides an excellent diffused source of the correct colour temperature.

The natural light coming through a window cannot, of course, be altered in direction, and it is therefore the subject which must be moved. One or more reflectors must be used to reduce contrast and to light up the shadows. If the sun shines on the subject directly it can be used as the keylight but the extreme contrast resulting from this is very difficult to reduce. A supplementary light source such as blue flashbulbs or electronic flash can be used to advantage. The lamp-to-subject distance must be carefully controlled so that the artificial source merely reduces contrast by lighting the shadows and does not compete with the principal source. Care must also be taken not to produce 'double-shadow' effects.

Artificial sources The only recommendations are that light sources of different colour temperature should not be mixed, and that the contrast of the lighting should not be excessive.

Ordinary domestic lamps should be replaced by lamps whose colour temperature is the same as that of the film. The exposure is best calculated by pointing the meter at the highlights and multiplying the calculated exposure by five or six. By using this system the exposure meter can be used at far lower light levels than by measuring reflected light. If the camera is on a rigid support, it is often worth moving the lamps about during the exposure so that the shadows are far less strongly defined.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

People To the photographer who is already familiar with composition and the balance of masses, colour harmony is the only problem.

With all subjects it is, as we have already seen, necessary to pay attention to the background. It must obviously be selected to suit individual subjects. Whilst a white or blue may be suitable for a child, a darker tone — grey or even black — is better for adults. A tint complementary to that of the subject is usually pleasing. The light flesh tints of a fair person are emphasized, for example, by blues and greens.

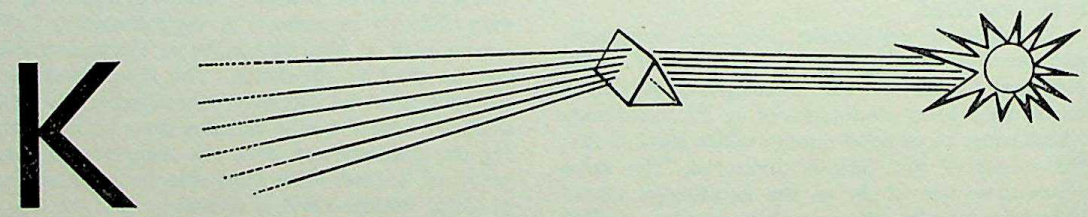
The lamps are arranged when the sitter is in position in front of the chosen background. If only a single lamp is available it must be somewhat above the level of the subject, and the shadows must be lit with a reflector. The reflector may be replaced by a second lamp but this must never approach the brightness of the key light which gives the modelling. Two differently placed lamps of similar strength will result in double shadows unless great care is taken in their placing. A further lamp may be used to light the hair, which usually appears too dark.

When photographing children, a different technique must be used. The heat and brilliance of Photoflood lamps may be disturbing and exposure times in the region of $\frac{1}{10}$ to 1 sec. are far too long. Flash is a suitable alternative. The general lighting level need only be low — just enough to arrange the lamps used as principal and fill-in, in the same way as continuous burning lamps are balanced. As the effective exposure with expendable lamps or electronic flash is 1/50 to 1/1,000 sec. there is little risk of movement. It is not even essential to have a synchronized shutter as the open flash method can be used. The shutter is set to 'B' and is opened just before the lamps are fired; it is then closed immediately. With this system the general lighting level should be kept as low as possible, and ordinary room lamps should be kept out of the picture area.

Another useful method is 'bounce-flash' where the lamp is pointed at the ceiling or a white wall instead of at the subject; this gives very soft, even lighting as opposed to the rather hard effect usually obtained with direct flash.

Still-life Moderation in the choice and quality of colour must be exercised in still-life work. The lighting need not necessarily be flat, and the principal subject can be emphasized by contrasting both colour and mass. Close-ups give excellent results. Back-lighting is also effective, as in black-and-white, giving strong reliefs. The exposure must be determined for the highlights after the shadows have been sufficiently lit with lamps or reflectors.

The subject can be lit with wholely diffused light; large reflectors are placed in front of the subject and several spot lamps are directed on to them so that no direct light reaches the subject — only the diffused light from the reflectors.

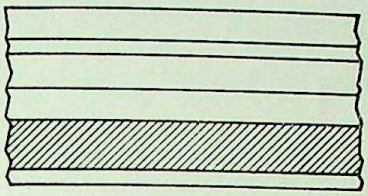


KODACHROME
(Reversal process)

The Kodachrome process was introduced by Eastman Kodak in 1935. At this time the processing procedure was extremely complex, but the procedure was greatly simplified in 1938 and it is this new process which will be described later. The marketing of this product — first in 8 and 16 mm. movie film and later 35 mm. film for miniature cameras — depended on the availability of sensitizing dyes which would not migrate from one layer to another, thus enabling a practical monopack film to be made with a structure as shown in Fig. 1 (see Colour Reproduction).

The reversal processing using coupler-containing partial colour developers demands such strict control that processing in most countries is only undertaken by Kodak. In the United States, however, a number of independent laboratories are also processing Kodachrome.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



1. Yellow layer, blue sensitive.
2. Yellow filter.
3. Magenta layer, green sensitive.
4. Cyan layer, red sensitive.
5. Support.
6. Anti-halo

Fig. 1.

The Film Kodachrome 16 mm. cine film and 35 mm. miniature film is available in two types.

Type D for daylight use, balanced for a colour temperature of 6,100°K.

Type A for artificial light, balanced for a colour temperature of 3,400°K (Photoflood lamps).

In the USA a film balanced for use with clear flashbulbs — Type F — has been marketed in the 35 mm. size.

The relative spectral sensitivity of the three layers for each type is shown in Fig. 2, from which

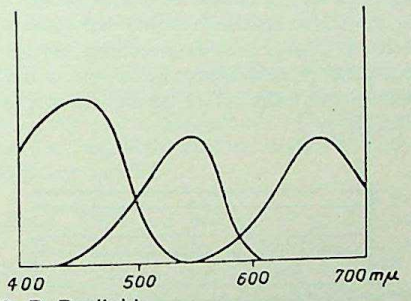


Fig. 2. D. Daylight.

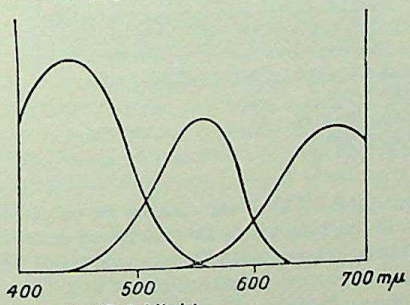


Fig. 3. A. Artificial light.

the difference in blue, green and red sensitivity of the three types can readily be seen.

The exposure index of Type A is 16 ASA in tungsten light and that of Type D is 10 to daylight. Owing to its high intrinsic blue sensitivity, Type A can readily be used in daylight (with an orange correction filter such as the Wratten 85) with no appreciable loss in sensitivity compared with Type D.

When Type D film is used in tungsten light (with a Wratten 80B correction filter) there is a loss (of 50 per cent) in effective speed, making the exposure index 5 ASA.

When photographs are taken using light sources either natural or artificial which differ appreciably from those for which the film is balanced, a colour cast will result. As this is a reversal process there is no stage, such as the printing one in a negative-positive system, where errors can be corrected. The tolerance of the film is quite adequate, however, provided that the manufacturer's recommendations are carefully adhered to. For professional work the use of correction filters over the camera lens is advisable, when the exposure conditions are non-standard.

From sensitometric studies (see Reversal Processes) the overall contrast has been found to be about 1·5. This gives high colour saturation and brilliance without reducing the exposure latitude excessively.

Processing The use of couplers present in the processing solutions rather than the emulsion demands the following procedure for Kodachrome:

1. 1st development to negative
2. 2nd development for cyan positive
   2nd development for yellow positive
   2nd development for magenta positive
3. Bleaching
4. Fixing.

Stage 2 actually consists of three separate successive development stages, each of which is preceded by a controlled exposure to light of a suitable colour to ensure accurate separation between the three images.

Various other stages are essential for the practical realization of this process. Their purpose is to avoid contamination of one layer with dye which should only be present in one of the other layers.

The final bleaching and fixing stages remove all the silver — both from the negative and colour development stages.

In more detail, the process comprises the simultaneous development in three layers of negative silver images. The film is then exposed to red light through the base, and this makes the residual halide in the cyan layer developable. This layer alone is then developed in a developer containing a colour developing agent and colour coupler (q.v.). At this stage a positive silver plus cyan dye image is formed.

A second exposure is then given, this time using blue light from the front of the pack to make the residual halide in the yellow layer developable. This layer is developed in a solution containing colour developing agent and yellow coupler, to give a positive image of silver plus yellow dye.

In the third stage, the magenta layer, which is

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

present between the two completely developed layers, is not readily re-exposed and so it is developed in a solution containing colour developing agent, magenta coupler and a *fogging agent*.

The bleaching stage converts all the developed silver to silver halide which is removed in the fixer to leave three positive dye images in cyan, yellow and magenta respectively (see p. 36).

KODACOLOR (Negative-positive process)

The Kodacolor negative-positive process was introduced by Eastman Kodak in 1942, and chronologically was the second commercial paper print process, Agfacolor having been introduced just before the war.

Since 1942 both the negative material and the paper have undergone several changes, as indicated below:

1942 Daylight balance negative with ordinary incorporated couplers. Silver colour correction mask. Conventional image order for paper, i.e. base — cyan layer — magenta layer — yellow layer. Processing carried out by Kodak.

1950–52 Replacement of simple couplers by coloured ones to give integral colour masking. Type A film available. Paper changed to inverse layer order — cyan outermost, yellow next to base.

1956 Release of processing data and paper to photofinishers in U S A.

NEGATIVE MATERIAL

a. Structure This has a conventional layer order. The magenta and cyan layers each contain colour couplers (see Eastmancolor Negative) for the production of colour correction masks. Only one type of film is currently made; for amateur use it has sufficient latitude to enable exposure to be made with daylight, flash (both electronic and bulbs) or with photofloods. Colour casts are corrected at the print stage. Exposure duration should be less than $\frac{1}{2}$ sec. For professional quality it is advisable to use correction filters for the various light sources used and to avoid exposures longer than 1/25 sec. For amateur use, exposures made indoors with electronic flash require the use of a Wratten 85 filter.

b. Processing Until 1955 processing was entirely in the hands of Eastman Kodak, but now facilities are available to independent laboratories and to individual photographers for processing Kodacolor using Process C22. Formulas have not been released.

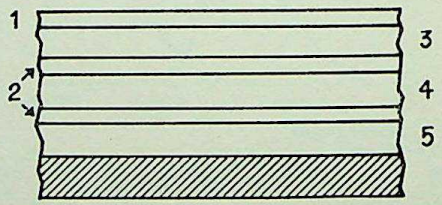
c. Printing Kodacolor negatives can be printed on normal black-and-white equipment provided that correction filters can be inserted in the light beam. For commercial work, however, this type of equipment is too slow and the automatic colour printers made by Kodak and most other manufacturers give large output and results which are satisfactory for most amateur purposes (see Printing).

KODACHROME II REVERSAL FILM

An improved version of standard daylight type Kodachrome first introduced in 1960. It is rated at 25 ASA and gives higher definition, improved colour rendering and has somewhat greater exposure latitude. Kodachrome II film is at present available only as a daylight type film for 8 mm. movie and 35 mm. still cameras.

PRINT PAPER

The layer order of the paper is not the traditional tripack one but is, in common with several other print materials, reversed to give the cyan image outermost. This procedure gives improved definition as the sharpness loss at the bottom of the pack primarily affects the yellow image where it is least noticeable.

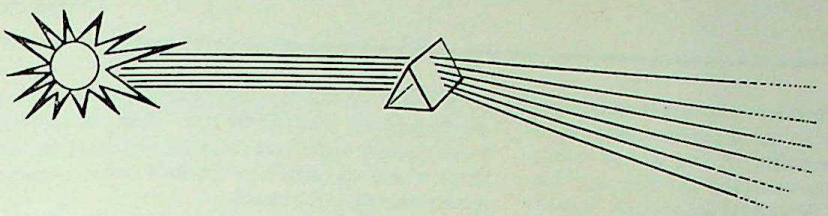


1 and 2. Layers of clear gelatin.
3. Cyan layer.
4. Magenta layer.
5. Yellow layer.

Processing The prints can be processed individually, in long strips in spirals, on continuous machines, or on automatic machines which handle racks loaded with strips or individual prints or in perforated baskets. The choice of system will depend on the class of work carried out: for amateur prints made on rolls any method can be used, but continuous band machines or long lengths in spirals are the most convenient. Where a wide variety of sizes is handled one of the other methods must be used.

For both negative and print processing Kodak supply kits of chemicals in a range of sizes suitable for all types of work and also pre-exposed process controls for checking the behaviour of solutions.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



L

LABORATORIES

Modern monochrome photography makes only small demands on laboratory space and equipment. This is not so with colour work where inconvenience and improvised equipment greatly reduce the output and prejudice quality.

A much wider range of equipment is required. The long processing sequences for both camera and printing materials demand a large number of tanks or dishes, each of which must have a definite location. They must also be well separated so that there is no risk of the contamination of one solution with another.

There is no great difference between the laboratory of the advanced amateur and that of the small professional except that the amateur, working alone, will require one moderate-sized dual purpose room, whereas the professional will find it more convenient to have separate, though smaller, rooms for handling camera materials and for printing respectively.

Location Whatever the size of the laboratory there are two essential requirements: complete light exclusion and good ventilation.

The room can be blacked-out with plywood shutters over the windows; these should have recessed edges so that the joints are covered, giving good light exclusion but at the same time allowing the shutter to be removed and the window opened for ventilation when the room is not in use. A light-trap maze at the entrance is an advantage, but if this is impracticable a curtain should be hung on each side of the door. Opaque plastic material is the best, and the curtain should overlap the opening completely on each side so that it is possible to enter or leave without light entering the room. Reasonable natural circulation is obtained with two light-tight ventilators — one low down near the door and the other high up in the window shutter.

For colour work the laboratory must be kept at a constant temperature. Unless thermostatic control is used, care must be taken in summer not to use too much heat or the room temperature is likely to exceed the working temperature of the solutions.

As the floor may frequently receive splashes of corrosive solution it should be covered with a plastic composition which is acid and alkali resistant. This composition coating should be continued for a few inches up the walls so that the room can be easily washed clean.

Lighting Although much of the work will be done in the dark, the workroom should be painted throughout in a uniform pale neutral colour with the ceiling white. This ensures the greatest evenness of illumination whenever absolute darkness is not essential.

Safe-lighting should be indirect with the lamp directed towards the ceiling. Filters should be available for all the materials handled, some of which require green filters, others brown. Sodium lighting may be used with papers designed with a sensitivity gap in the orange. A hand lamp also fitted with filters should be available for checking filters, packages and the clock with localized fairly high intensity light.

All electrical installations must be suitably earthed and moisture-proofed. Wiring must be heavy enough to carry the necessary current, not only from the point of view of safety, but to avoid voltage fluctuations when the load is switched on.

Equipment Like any other photographic laboratory, the colour workroom must have a sink with running water and a drain. The sink should be large enough to contain the sequence of small tanks or dishes used for the complete process. The tanks should be in a thermostatically controlled water or air bath. The solutions must be kept at a constant temperature — within $\frac{1}{2}$°F for developers. If the mains water is likely to exceed 65°F (or 75°F for some processes) some form of refrigeration must be provided. The sink should be lined with a corrosion resistant material. A large number of plastics and acid resistant paints are now available for this purpose.

In addition to benches for the enlarger and other permanent pieces of equipment, a fairly large workbench or table should be available. This may be an extension of the sink, arranged to fold against the wall when not in use, or it may be a simple long narrow table. In either case it should be covered with easily-cleaned waterproof plastic material.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Plastic-covered wooden furniture is convenient and it is advisable to use the minimum amount both to ensure convenient working and to reduce to the minimum the tendency to bring sensitive material or chemicals into the laboratory, both of which must be kept dry and as far from each other as possible.

The processing tanks are chosen according to the size of film used and the quantity. For sheet film, stainless steel, hard rubber or plastic tanks of between 2 and 15 litres are available. Special care should be taken with the bleach tank as some types of stainless steel are not resistant to ferricyanide or dichromate solutions.

Printing and enlarging For contact printing a normal black-and-white printing box may be used provided a holder for correction filters can be incorporated. To reduce the size of filters required, a 2 × 2 in. projector may be mounted outside the printing box; the light is projected through a hole in the side of the box and reflected up to the printing plane. The whole unit must, of course, be made light-tight, and to avoid overheating the filters which are carried in the slide carrier, a low-power lamp should be used.

A standard black-and-white enlarger may be used provided it is fitted with a holder to carry the printing filters between the lamp and the condenser — the most suitable location for subtractive printing. For additive printing a slide or disc carrying the three filters in front of the lens is used. In this case three separate exposures are made, and to avoid confusion it is helpful to use three timers. A better system is to use a rotating filter disc and to alter the iris diaphragm to obtain constant exposure; this can be used with any type of enlarger.

The voltage to the lamps should be controlled with either a constant voltage transformer or with a manual control and voltmeter across the lamp to obtain consistent results.

LENSES

Introductory note Whilst professional cinematography may use special optical systems incorporating prism blocks or multiple lenses for both camera and projection work, this aspect will not be dealth with here where we are more concerned with the general characteristics of lenses for colour photography.

Although lenses which have been used for black-and-white work are generally suitable for colour work also, this reassuring statement makes no difference at all to the interest in the study of the optical characteristics required in colour work.

A wide-aperture lens is often used because colour films tend to be somewhat slow, but it is essential that the increase in light transmission is not paid for too dearly by a decrease in image quality.

The sharpness of the image formed by a lens is controlled by the degree of correction of the faults or aberrations of a lens; only a brief description of those encountered in colour work will be given.

To illustrate them the best method is to refer to a simple converging lens having spherical surfaces: in this case the aberrations cannot be corrected and are particularly noticeable.

Aberrations

1. Light rays from a monochromatic point source on the lens axis pass through different parts of the lens, assuming it is not stopped down. After refraction the rays from different parts of the lens do not converge at the same point on the lens axis; those from the outer portions of the lens reaching the axis nearer the lens than those from the inner areas.

No matter where a sensitive surface is placed a sharp image cannot be obtained — only a circular patch. This defect, known as *spherical aberration*, becomes more noticeable as the diameter of the lens increases relative to its focal length.

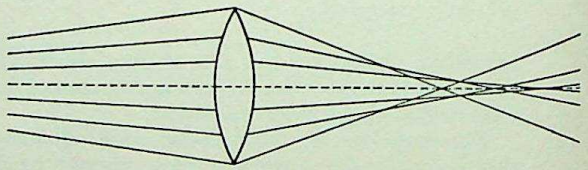
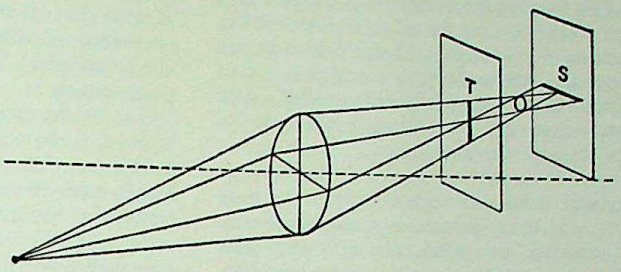


Fig. 1. Spherical aberration.

2. Using the same lens, this time suitably stopped down, a narrow light beam passing obliquely through the lens is not brought to a point focus. Instead of converging to a well defined point, the light forms two small, sharp, bright lines S and T, perpendicular to each other and in different planes. Between these two sharp perpendicular lines is the intermediate focusing point O where neither is particularly well defined. This defect is called *astigmatism*.
3. With the diaphragm still in place but replacing the point source by a large flat object perpendicular to the lens axis, an image will be obtained which is not flat but is curved, the concave face being towards the lens.
   This defect is known as *curvature of field* and the flat sensitive surface can only receive a sharp image over a part of its surface.
4. With the lens no longer stopped down, the light rays, instead of forming a narrow beam

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Fig. 2. Astigmatism.



when passing through the lens obliquely, form a broad beam, the image produced being a diffuse area consisting of a bright centre with an unsymmetrical plume or halo. The image is said to suffer from *coma*.

5. Finally, away from the lens axis, the image of a straight line is not in fact straight; the sides of a rectangle are deformed, the deformation increasing with the distance from the axis. This defect — *distortion* — does not affect the sharpness of the image but alters its shape.
6. If instead of monochromatic light a light mixture such as daylight is used, the normal process of refraction splits the light into an innumerable number of different light beams which are brought to a focus at different points. As violet light is refracted more than red light, it is brought to a focus closer to the lens than is the light of longer wavelength. The invisible ultra-violet radiation forms an image even closer to the lens than the violet whilst the infra-red, as one would expect, is focused beyond the deep red. This type of colour defect is known as chromatic aberration; there is a further type of colour defect in which images of different colours are of different size.

Correction By the use of lenses of different character (convergent and divergent), of different shape, and made with glasses of varying optical properties, the aberrations can largely be corrected by introducing similar ones of opposite character during the passage of light through the lens. The disposition of the lenses or group of lenses and their positions relative to the iris diaphragm have an important bearing on the image quality.

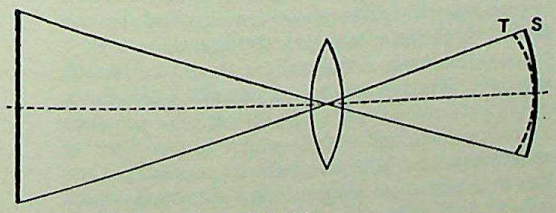


Fig. 3. Curvature of Field.

In black-and-white work a considerable amount of correction is required; but for colour work an increase in aperture, although highly desirable, is useless if also accompanied by certain faults (spherical aberration and coma) which may not have been adequately corrected.

For colour work it is mainly the residual chromatic aberrations which must be eliminated as far as possible. If this is not done colour fringing may be noticed, particularly on sharply defined light and dark areas.

Before the present wide interest in colour photography the Graphic Arts industry was fully conscious of the necessity for a very high degree of colour correction in lenses. For use in multi-colour work achromatic lenses were not sufficient and it was necessary to correct for both size and focus for three colours instead of the usual two. Such lenses are known as apochromats.

The aperture of such lenses is usually quite low, about $f/10$ for focusing and $f/22$ or $f/32$ for the actual exposure. Some recent $f/4.5$ lenses are claimed to have apochromatic correction. Modern wide-aperture camera lenses, working at $f/2$, $f/1{\cdot}4$ or even $f/1$, obviously demand a very different approach to the problems of correction.

Advantage must be taken of new techniques; of particular note in this respect are the new glasses, which manufacturers are always placing at the disposal of lens computers. The most interesting are those which have at the same time a high refractive index comparable with the extra dense flints but a very low dispersion more usually associated with the crowns. Rare earth oxides (lanthanum for example) when added to the melt can produce glasses with a wide variety of properties.

Today one of the greatest aids to the designer of a lens is the electronic computer by means of which the laborious calculations previously necessary to check each change in lens formula can be reduced to a matter of minutes and so greatly accelerate the production of a suitable combination. The speed and reliability of these calculations encourage the construction of a prototype whose performance can be thoroughly checked; interesting information can then be

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

obtained by varying the basic optical properties of the lens (surface curvature, refractive index, separation of elements, etc). In this field as in any other, it is the human factor in research that is of prime importance, interpreting the available data and converting the theoretical results into a practical piece of equipment.

Vignetting It can be seen that from the construction of a lens, particularly one containing several elements, that whilst the axial rays pass through without hindrance, the oblique ones may be cut off to a greater or less extent by the diaphragm and the lens mount up to a point where the apertures of the two no longer coincide.

In black-and-white work the resulting reduction in marginal brightness is tolerable until it results in an irritating shadow in the corners of the image.

With colour however, the situation is far more critical for there is a noticeable reduction in colour accuracy as the exposure level falls off towards the edges before the density difference becomes apparent. Other things being equal, vignetting is more apparent at large apertures and an improvement in the performance of a lens can be obtained by stopping down.

This is a further factor which must be considered in choosing a lens for colour work.

Coating In recent years it has become common practice to treat the air-glass surfaces of photographic objectives with an anti-reflection layer. This treatment, commonly known as coating and sometimes blooming, has two main advantages; in the first place the reduction of reflections appreciably increases the light transmission and secondly, by cutting down spurious internal reflections in the lens, the image contrast is appreciably increased, particularly when a bright light is present in the field of view.

In colour the benefit from both of these factors cannot be ignored but the method used for coating must be selected so that the image quality is not adversely affected.

The usual method is to deposit a thin transparent fluoride layer on the lens surface (cryolite, magnesium fluoride) by vacuum evaporation; the elimination of reflections depends on certain properties of thin layers which under certain conditions produce a readily visible interference phenomenon.

The mathematical expressions involved in the calculation of the layer thickness bring in the wavelength of the appropriate light beam. The elimination of reflections cannot be obtained simultaneously for all the monochromatic colours making up white light. Naturally it is usual to arrange the maximum transmission and hence the layer thickness to correspond to the maximum sensitivity of panchromatic emulsions. These yellow-green radiations are most readily transmitted and the slight residual reflected light has a predominance of blue and red, thereby giving the lenses a generally purple appearance.

Coating is therefore not a completely neutral process as far as white light is concerned.

In the case of simple lenses the effect of coating is relatively small. When the number of glass-air surfaces rises, however, and this is inevitable with wide-aperture and wide-angle or variable focus lenses, there is sometimes a considerable colour cast caused by the coating process. The effect of such a colour cast may be exaggerated by alternating sequences taken through lenses having the defect to a different degree, that is, with a camera designed for interchangeable lenses.

Here again colour is less tolerant than black-and-white and to avoid degrading colours it is advisable to adjust the coating process to increase the transmission of blue light: the yellows then accompanying the light at the red end of the visible spectrum, being preferentially reflected with the purple.

The foregoing notes indicate the desirability of careful selection of lenses for colour work; only well-tested types can be depended upon to give reliable quality under all conditions. With regard to quality, the increasing number of amateur photographers and cinematographers is an incentive to manufacturers to maintain and increase their standards and the benefits of the developments for the colour worker are also available for black-and-white.

LIGHT

Even the most eminent physicists cannot give a complete answer to the question 'what is light ?', and it is not the purpose of this section to enter this controversy, but to discuss the properties of light which are of interest to the colour photographer. Only the classical wave-motion theory of light will be considered, and although this is far from new, it does enable the mechanism of many phenomena to be understood in a relatively simple way.

Electro-magnetic and light waves When a charged particle is in movement it produces an electric field and a magnetic field which are both propagated through space at a high, though finite, velocity. When a changing potential difference exists between the ends of a metal wire the conductivity electrons of the metal are subject to movement, and the aerial thus produced relays through space an electro-magnetic wave which travels with a velocity of about 186,000 miles per

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

second — that is, about a million times faster than sound. In a similar way, when a metallic wire is made white hot, the peripheral electrons of the metal are displaced and this light source emits electro-magnetic waves similar to radio waves with the difference that these waves affect the retina. In other words, although their method of production and reception are completely different, light waves and radio waves are the same type of electro-magnetic wave. Furthermore, as we shall see, X-rays and γ-rays emitted by certain radio-active substances, or present in cosmic rays, are also electro-magnetic. Although this is of no direct interest to the photographer, it is useful to know how light waves are related to other electro-magnetic waves.

Light waves, like sound waves and other periodic phenomena, can be identified by their period, or by the inverse, *frequency*. Thus alternating current of 50 cycles/sec. has a period of 1/50 sec. and a frequency of 50 per sec. A radio aerial receiving a potential difference of this frequency will generate electro-magnetic waves which also have a period of 1/50 sec. and a frequency of 50 per sec. Furthermore, electro-magnetic waves can also be defined by the distance travelled in one cycle or period, $\lambda = VT$ (where V is the velocity and T is the period; this distance is termed *wavelength*. Thus in our example, and taking the velocity of propagation as 300,000 Km/sec. (electro-magnetic waves are usually defined in metric units), the wavelength will be $300{,}000 \times 1/50 = 6{,}000$ Km. (i.e. 6 million metres) The radio waves used in practice are much shorter than this, varying from 2,000 metres down to 10 metres for amplitude modulation and to centimetre waves for television and frequency modulated sound. These correspond to frequencies from a few hundred to over a million times greater than the example. As the frequency increases the wavelength passes through the centimetre and millimetre ranges for which special techniques are necessary. Beyond this, the waves are not produced by the movements of electrons in a conductor but by the vibration of atoms or groups of atoms in the molecule. This group of electro-magnetic waves is known as infra-red radiation, whose wavelength varies from a fraction of a millimetre to about 0·7 microns (the micron, designated by the Greek letter μ, is one-thousandth of a millimetre or millionth of a metre). Infra-red waves are detected by the rise in temperature which generally occurs when they are absorbed. Electro-magnetic waves of even higher frequency are produced by the peripheral electrons of atoms. Radiations of wavelength between 0·7 and 0·4μ are received by the eye (and also by the panchromatic photographic emulsion). This is the visible band. Beyond 0·4μ the photographic emulsion is still sensitive, but not the eye. This is the ultra-violet region, extending from 0·4μ down to a few millimicrons. Ordinary photographic plates can only be used at wavelengths greater than 0·24μ as below this wavelength the gelatin absorption cuts off the radiation. At still shorter wavelengths the waves are produced by the inner electrons or even by the material of the nucleus. The region beyond the ultra-violet is the X-ray region and then come the γ-rays. Altogether the range of electro-magnetic waves from the γ-rays to the long wavelength radio waves covers, in acoustical terms, 70 octaves (an octave being a 2 : 1 frequency range) and the eye is sensitive to a region covering rather less than one octave. It is this octave which plays a fundamental rôle in life, and is termed light.

Velocity of light, absolute refractive index In a vacuum, all electro-magnetic waves, including light waves, travel at a uniform velocity 'c' which is very close to 300,000 Km/sec. In all transparent media other than a vacuum the electrical field of the electro-magnetic wave acts on charged particles (electrons, nuclei, ions, etc) and the effect of this interaction is to reduce the velocity of the wave, the reduction being more pronounced at longer wavelengths (at least when no absorption phenomena are involved). This ratio $N = c/V$ is called the *absolute refractive index* of the medium at a stated frequency. In gases, particularly air, the velocity V of light is only slightly different from the velocity 'c' in a vacuum, and hardly varies with wavelength (the absolute refractive index of air is in the order of 1·0003). Gases are said to be only slightly 'refractive' and slightly 'dispersive'. For water N is about 4/3 and for glass about 3/2; diamond is almost 2. The slightly dispersive glasses such as the crowns have a difference in refractive index of about 0·008 from one end of the visible spectrum to the other. The very dispersive glasses such as the dense flints have, however, a variation of 0·020 over the same range. It should be noted in connection with this phenomenon of dispersion and velocity, that if frequency is an essential characteristic of the electro-magnetic wave then the wavelength $\lambda = VT$ plays a part in defining the medium as V varies with the medium. Thus the wavelength limits of the visible spectrum of about 0·4 – 0·7μ in a vacuum or in air drop respectively is 0·27, and 0·47 in a glass of refractive index 1·5. When the term wavelength is used without stipulating the medium, it is always assumed that the medium is a vacuum or air, the latter differing by only 0·03 per cent.

Reflection and refraction When light reaches the surface of an object, part of the light penetrates the surface and the luminous energy is the more rapidly absorbed and converted to heat as

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

the transparency of the object decreases (this will be considered later). The remainder of the light is reflected back in all directions by minute irregularities in the surface. It is this *diffuse reflection* of natural and artificial light which makes the world visible and photography possible. In the special case when the object has a perfectly polished surface, the light is reflected in only one direction clearly defined by physical laws. Similarly, light penetrates a transparent object in only one direction which is also the subject of laws. Before dealing with these notable laws of Descartes on reflection and refraction which are indispensable to the designer, but not to the user, of a lens, it should be realized that perfectly smooth surfaces, such as a still pool, are relatively rare in nature, slightly diffusing ones being much more common. They reflect in neither a perfectly diffuse way, nor in a way following Descartes' laws but in an intermediate way giving reflections which can be awkward in photography.

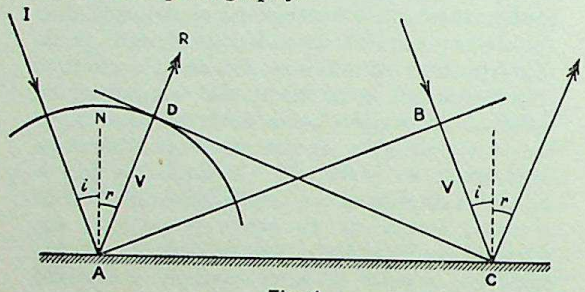


Fig. 1.

In Fig. 1, take the case of a light wave AB striking the surface of a mirror. Assume that the point B is separated from the mirror (according to the direction of the wave) by a distance BC equal to V × 1 sec. where V is the velocity of the wave. We can imagine that by the time point B of the wave reaches point C of the mirror (taking 1 sec.) the point A will already have returned a distance AD equal to V × 1 sec. and that at this moment the wave will occupy a position CD, symmetrical with the position AB about a plane normal to the mirror and normal to the plane of the figure. If the direction of propagation of the wave is termed 'a light ray' (which will be considered more closely later) it can be seen that:

1. A reflected ray such as AR is in a plane limited by corresponding incident ray IA and the normal to the mirror AN at the point of incidence A, called the plane of incidence (the plane of the figure). This is the first of Descartes' laws of reflection.
2. A reflected ray such as AR is symmetrical with the corresponding incident ray 1A about the normal to the mirror AN at the point of incidence. In other words, the angle of reflection is equal to the angle of incidence. This is Descartes' second law of reflection.

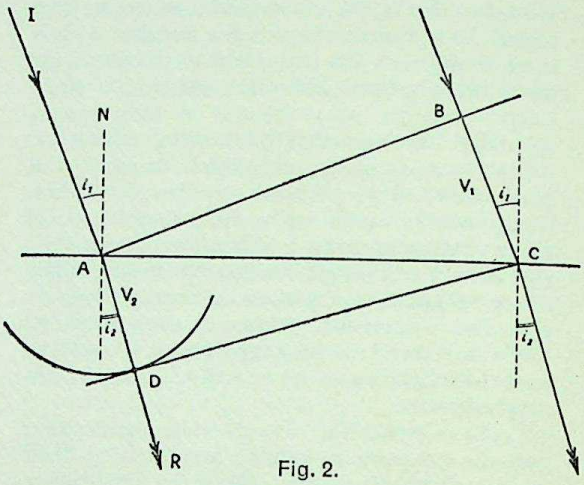


Fig. 2.

Now take a light wave AB reaching the dividing surface between two transparent media (Fig. 2) in which the velocity of light is V_1 and V_2 respectively. Assume that the distance BC of the point B from the surface at C is (depending on the direction of the wave) $V_1 \times 1$ sec. Again it can be seen that when the point B of the wave has reached point C of the interface (which takes 1 sec.) the point A will have passed through the second medium a distance $AD = V_2 \times 1$ sec., and that at this moment the wave will occupy a position CD which is not parallel to AB. Once more considering light rays it can be seen that:

1. A refracted light ray such as AR, like a reflected ray, is in the same plane IAN as the incident ray. This is the first of Descartes' laws of refraction.
2. If we call i_1 and i_2 the angles of incidence and refraction respectively, then:

$$\frac{\sin i_1}{\sin i_2} = \frac{V_1}{V_2}$$

In other words the ratio remains constant although the angle of incidence may vary. This is the second of Descartes' laws of refraction.

Knowing that the absolute refractive indices of the two media under consideration are respectively:

$$N_1 = \frac{c}{V_1} \text{ and } N_2 = \frac{c}{V_2}$$

it follows that:

$$\frac{\sin i_1}{\sin i_2} = \frac{V_1}{V^2} = \frac{N_2}{N_1}$$

If N_1 is less than N_2, i_1 is greater than i_2; in other words, when a light ray penetrates a more refringent medium it is turned towards the normal (Fig. 3). On the contrary if N_1 is greater than N_2, i_1 is less than i_2 and therefore a light ray penetrating a less refringent medium is turned away from the normal. In this latter case i_2 becomes equal to 90° when the angle of incidence reaches

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

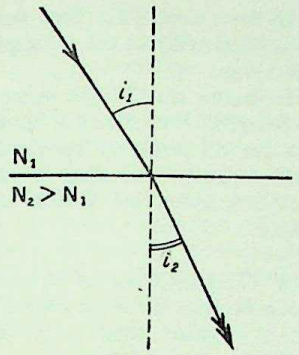


Fig. 3.

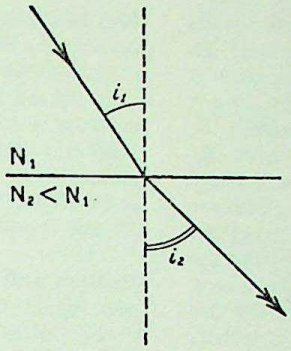


Fig. 4.

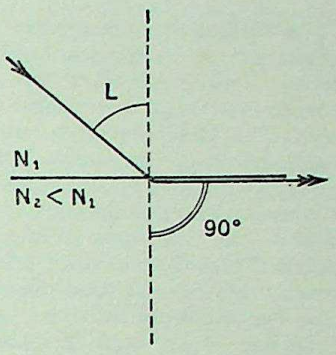


Fig. 5.

a critical value L such that:

$$\sin L = \frac{N_2}{N_1} \text{ (Fig. 5).}$$

If the angle of incidence increases still further the light ray can no longer pass into the second medium and is reflected (total internal reflection). A light ray, therefore, can always penetrate a more refractive medium (for example sunlight can always pass into the sea) but it can only penetrate a less refractive medium if the angle of incidence is less than the critical value L defined above and called the critical angle or angle of total reflection. This phenomenon of total reflection is used for example in certain prisms such as the one shown in Fig. 6, for which the angle of incidence on to the face AB is 45°, whilst for glass and air the critical angle is about 42°.

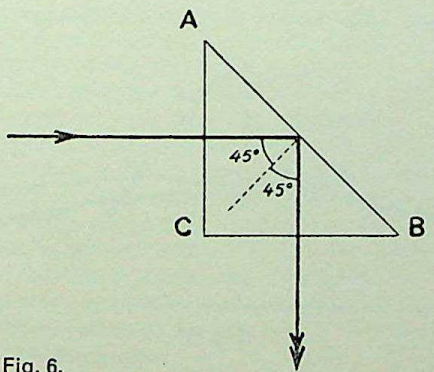


Fig. 6.

The ratio $\frac{V_1}{V_2} = \frac{N_2}{N_1} = n_{2/1}$

is termed the relative refractive index of the second medium compared with the first (the absolute index:

$$N = \frac{c}{V}$$

is the index with reference to a vacuum). As the index of air is 1·0003 the index of a medium relative to air is within 3/10,000 of its absolute index. When an index is given with no reference it is assumed that the index refers to a comparison with air, as this is the most directly accessible medium.

If the dispersive properties of two media are not identical, that is if N_1 and N_2 vary differently as a function of the frequency, the relative refractive index

$$n_{2/1} = \frac{N_2}{N_1}$$

also varies with the frequency. Thus as air is very slightly dispersive, the relative index of liquids and solids relative to air always varies with frequency. Consequently there is a variation of the index relative to air in the region of the absolute index.

With reflection, frequency need not be considered as $i = r$ whatever the wavelength, but with refraction frequency must always be considered, as the ratio

$$\frac{\sin i_1}{\sin i_2} = n_{2/1}$$

varies with frequency. Thus with an interface of air to water or air to glass the relative index of the water or glass to that of air increases with the frequency and under these conditions for a given angle of incidence i_1, the angle of refraction i_2, will be smaller as the wavelength is shorter (Fig. 7). This phenomenon is used in the prism spectroscope which will be discussed later.

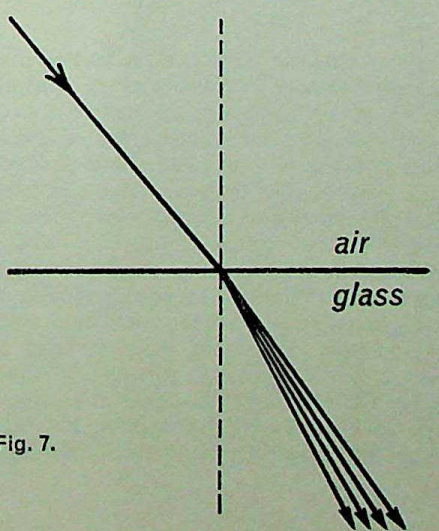


Fig. 7.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

The surface of a transparent medium always reflects part of the incident luminous energy. In other words refraction is always accompanied by reflection (although the opposite is obviously not true). The Descartes' laws must therefore be completed from the energy point of view by knowledge of the *reflection factor* — the percentage of luminous energy reflected, and the *transmission factor* — the percentage of luminous energy refracted. These factors can be calculated from the known behaviour of electro-magnetic light waves. They depend on the refractive indices of the two media and on the angle of incidence. Generally the reflection factor r becomes greater as the difference between the two indices becomes greater and as the angle of incidence increases. Fig. 8 illustrates the variation of the reflection factor as a function of the angle of incidence for an air glass interface. It is seen that although r is small at angles of incidence less than 40°, it increases rapidly with a larger angle of incidence. This is why reflections become stronger as the lighting angle decreases.

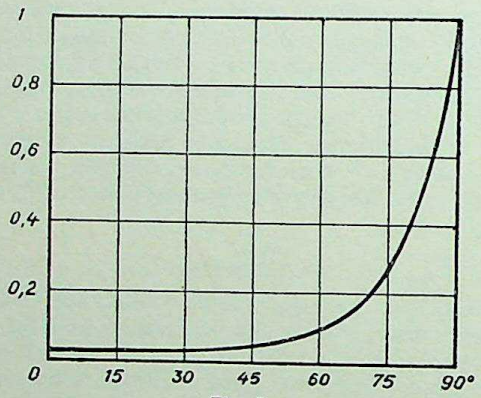


Fig. 8.

At normal incidence the expression of the reflection factor is simple:

$$r_n = \left(\frac{n_1 - n}{n_1 + n}\right)^2$$

n_1 and n being the indices of the two media (the transmission factor itself is obviously equal to $1-r$ following the principle of conservation of energy). Thus for air and glass $r_n = 0{\cdot}04$, for air and water $r_n = 0{\cdot}02$, for water and glass $r_n = 0{\cdot}0035$ (this is why a piece of glass immersed in water is barely visible; it scatters only a small amount of luminous energy). In an optical instrument, such as a photographic lens, there is therefore at least a 4 per cent loss by reflection at each surface of the lens (r_n is the same for the two interfaces of a lens as it remains unchanged when n_1 and n are inverted, that is when the direction of the light is reversed), and the brilliance of the instrument drops considerably as the number of lenses increases. It is now possible to reduce these reflection losses enormously by treating the lens surfaces with a thin anti-reflection layer; the principle of this will be discussed later.

It should finally be noted that if the second medium is the less refringent, the reflection factor reaches a value of 1 for an angle of incidence greater than the critical angle, according to the principle of total internal reflection which has already been discussed.

Prisms and spectra The splitting up of complex light by refraction occurs whenever a lens is used, and is shown by colour fringing of the image. This fault of chromatic aberration is a difficulty which must be overcome with all optical instruments. It can be overcome by replacing the simple lens by an achromatic system of two lenses in which the chromatic aberration of the one is cancelled out by that of the other.

On the other hand the splitting of complex light by refraction is used in certain instruments such as the prism spectroscope which is used to study the composition of a given light. Fig. 9 shows the paths of two light rays of different frequency passing through a glass prism in air. As we have already seen, for a given angle of incidence, i, the angle of refraction, r, becomes smaller as the frequency increases. Thus at the first face of the prism the shorter wavelengths are bent more towards the base of the prism. The second face of the prism accentuates this effect, and overall the beam R_1 of shorter wavelength is bent more than beam R_2, as the difference in wavelength increases and the dispersion of the glass becomes greater.

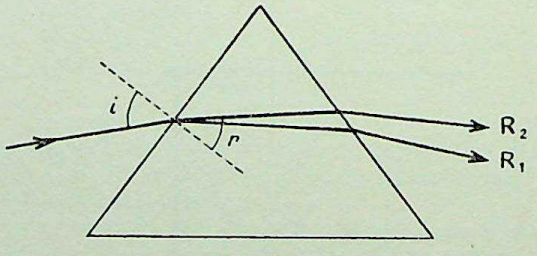


Fig. 9.

It was with such a prism that Newton first broke sunlight down into its component colours. He noted that sunlight produces a continuous spectrum (this is not strictly true as we shall see later) extending from violet to red, the violet end of the spectrum being towards the base of the prism and therefore being of shorter wavelength. The approximate wavelengths corresponding to various colours are shown below; they are subject to variation according to the observer:

violet	0·41 to 0·44μ
blue	0·44 to 0·50μ

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

green	0·50 to 0·57μ
yellow	0·57 to 0·59μ
orange	0·59 to 0·61μ
red	0·61 to 0·72μ

It has already been seen that beyond 0·41μ is the ultra-violet which although invisible is capable of affecting a photographic emulsion. Below 0·35μ the radiations are absorbed by ordinary glass, so it is necessary to use prisms and lenses of quartz. Sunlight contains no radiations below 0·30μ because of atmospheric absorption, but various artificial sources emit shorter wavelengths. Recording becomes difficult below 0·24μ due to absorption by gelatin, whilst below 0·185μ even the air absorbs strongly.

At the other end of the spectrum with the wavelength exceeding about 0·72μ is the infra-red region whose radiations are also invisible but capable of affecting special photographic emulsions. Beyond 1 to 2μ, radiations are absorbed by glass, and photographic emulsions are no longer suitable for recording — which becomes much more difficult.

Spectral energy curve. White light. Colour temperature The various regions of the solar spectrum do not have the same energy level, consequently, to fully define sunlight (or any other complex radiation) a spectral energy curve must be plotted showing the energy level in the various spectral regions. With sunlight this spectral energy curve has a maximum in the blue (Fig. 10) provided that the wavelength is plotted on the abscissa. An incandescent lamp, like the sun, gives a continuous spectrum but as Fig. 10 shows, the appearance of the spectral energy curve is quite different. The energy gradually increases with the wavelength as light from an incandescent lamp is far richer in red and poorer in blue and violet than is sunlight. When these two light sources are observed independently, however, each appears white which shows that the subjective sensation of white is not well defined. In fact any luminous source having a continuous spectrum over the visible range and which is not excessively irregular will appear white as long as it is not compared directly with sunlight.

Physicists have conceived an ideal light source — the black body radiator whose properties depend solely on the temperature to which it is raised. This is approximated by a very small sized hole made in the wall of a furnace. At very low temperatures this hole is completely black. Then as the temperature of the radiator is raised, it first emits infra red and then red (in the vicinity of 500°C), to which are added successively yellow, green, blue, violet and finally ultra-violet (which appears at about 1,800°C).

Fig. 11 shows the relationship of the spectral energy curve of a black body and the absolute

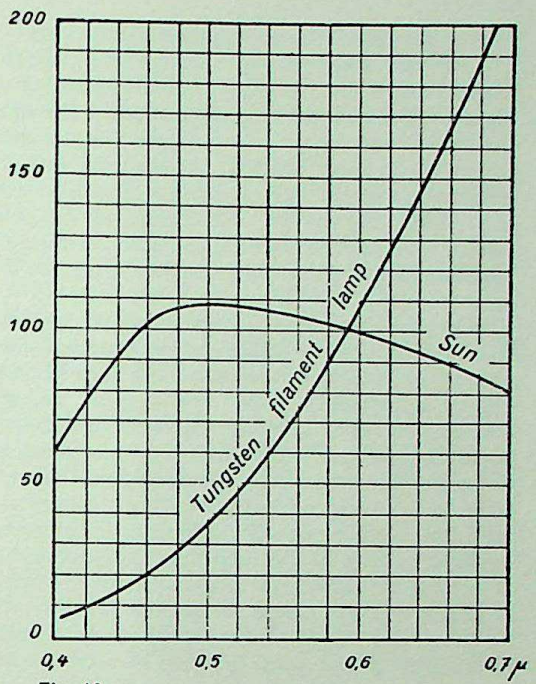


Fig. 10.

temperature (degrees K = degrees C plus 273°), the value 100 being arbitrarily given to the portion of each curve at a wavelength of 0·56μ. Above 5,000°K, the radiations become richer at the blue end compared with the red end of the spectrum, the light becoming bluish, whereas the converse is

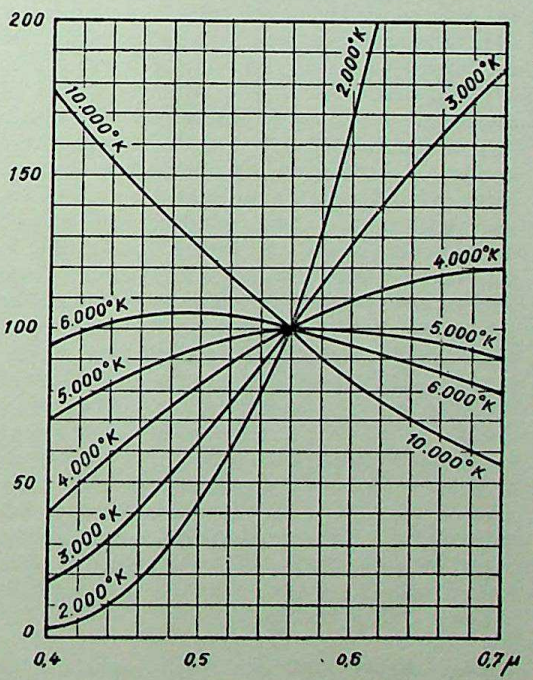


Fig. 11.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

true below 5,000°K when the light is yellowish.

To define a source of white light, it is convenient to compare its spectral energy curve with that of a black body radiator having a similar curve through the visible spectrum. The absolute temperature of the black body radiator is called the colour temperature of the light source under consideration. Thus the colour temperature of midday summer sunlight is about 5,400°K whilst that of incandescent tungsten lamps varies from 2,500 to 3,400°K.

Materials for direct colour photography are balanced for a given colour temperature and the photograph will be off-balance if the illumination differs appreciably from the correct colour temperature (in other words with a different composition) provided no precautions have been taken to correct this with filters (yellow-orange filters to lower the colour temperature, bluish filters to raise it). This occurs, for example, if ordinary daylight balance film is used to take photographs at sunset, for the colour temperature of the light is then very much lower, the reasons for this will be dealt with later. However, when an artistic effect is required regardless of correct colour rendering, any distortion is permissible, for the matter then passes into the realm of personal taste.

Monochromatic light Mercury, cadmium, hydrogen and similar lamps do not in fact give a continuous spectrum but a certain number of 'lines' at well defined wavelengths. In other words the light emitted by these lamps is not a mixture of an infinite range of radiations but is a mixture of a limited number of monochromatic radiations. With suitable filters it is possible to absorb all radiations but one and in this way monochromatic light is obtained, whereas with white light, filters always pass quite a wide band which is far from being monochromatic although it may seem so to the eye. The sodium lamp, which only emits a pair of lines (which have very similar wavelengths) in the orange-yellow, gives virtually monochromatic light by itself without the necessity for filters. For such monochromatic radiations, for mixtures of monochromatic radiations, and for the general case of discontinuous spectra between the limits of visibility, it is obvious that no colour temperature can be given. Such lighting may falsify colour rendering for, being used to sunlight, it is natural to judge a colour as it appears in white or nearly white light. A piece of red cloth appears red because in white light it reflects the red radiations, absorbing the others. When illuminated with sodium light or any other light having no red in it, the cloth will appear black.

Visual colour addition White light can be broken down into its constituent wavelengths and conversely it can be reconstituted from a mixture of these radiations. But what is even more remarkable is that a mixture of only three coloured lights, suitably selected and regulated, can produce white light or virtually any required colour. This three-colour additivity which is the basis of colour photography, depends upon the construction of the eye, which is fully described in the section on Vision.

Absorption, filters It has already been shown that when electro-magnetic waves pass through any transparent medium other than a vacuum their electric field results in a disturbance of the charged particles present in the medium. These particles, unlike the electrons of the metals, are not free and have a particular frequency of vibration just like a piano wire or a suspension bridge. If the frequency of the light wave happens to be close to that of the particles, the amplitude of the movement of the particles in the electric field becomes very great. The energy of the particle is converted into thermal energy due to friction, or in other words the medium strongly absorbs radiations of the frequency which brings about this effect. Thus glass, which is for all practical purposes transparent in the visible region, absorbs both ultra-violet and infra-red. If absorption takes place in the visible region the colour of the object by transmitted light is complementary to the colour absorbed. This occurs with a solution of copper sulphate and with all filters which are used in photography.

For each unit of thickness dx of the absorbing medium, the relative reduction of the luminous flux $d\Phi/\Phi$ is proportional to $dx: d\Phi/\Phi = -c.dx$, where c is a constant depending upon the medium and the wavelength under consideration. From the preceding relation we can see: $\text{Log } \Phi/\Phi_0 = c.x$, where Φ_0 is the initial flux and Φ the remaining flux after passing through thickness x of the medium. Generally common logarithms are preferred to napierian, giving: $\log \Phi/\Phi_0 = -k.x$, where k is a constant proportional to c. In the case of filters the transmission is expressed as $\Phi/\Phi_0 = 10^{-kx}$, and the optical density as $-\log \Phi/\Phi_0 = \log \Phi_0/\Phi = k.x$. This optical density is a convenient value as it is proportional to the thickness x of the filter. For all colour filters the transmission and optical density obviously vary with the wavelength. It is, however, possible to prepare neutral filters whose transmission remains substantially constant throughout the spectrum.

Unlike glass, certain substances, such as hydrogen or sodium vapour, have very sharp absorption bands which coincide with the emission bands produced by a discharge through the same gas. The solar and terrestrial atmospheres both result in considerable absorption of the sun's light in the form of lines which were first noted by Fraun-

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

höfer. The eight principal absorption lines were identified by the first eight letters of the alphabet. This system is still used to some extent. The following show the wavelength of the eight lines and the elements which are responsible for each.

A	0·7594μ	oxygen
B	0·6867μ	oxygen
C	0·6563μ	hydrogen
D	0·5896$_\mu$&0·5890μ	sodium
E	0·5270μ	iron
F	0·4861μ	hydrogen
G	0·4308μ	iron
H	0·3968μ	calcium

It is usual to define the dispersion characteristics of glass by the expression

$$\frac{n_D - 1}{n_F - n_C}$$

(where n_D, n_F and n_C are respectively the indices for the lines D, F and C), called a 'dispersion coefficient'.

Diffusion When light passes through a turbid, foggy, smoky atmosphere or through sea or river water, the suspended particles absorb a part of the light and diffuse a further part — that is it is scattered in all directions. If the particles are large compared with the wavelength (larger than 1/100 mm.) all frequencies are equally diffused and under these conditions white incident light will result in white diffused light. This is the case with fog and dense smoke and also with the majority of sea and river water (with water the light is always tinted by absorption; the blue colour of the sea being due almost entirely to the fact that the diffused light at the surface has passed through a certain thickness of water, whose transmission maximum is in the blue-green).

If the particles are small relative to the wavelength which is of the order of a thousandth of a millimetre, the shorter wavelengths are diffused more following Rayleigh's law, which states that the coefficient of diffusion is inversely proportional to the wavelength to the power of 4 (it is therefore sixteen times greater at 0·4μ than it is at 0·8μ). Under these conditions, with incident white light the diffused light is blue and the transmitted light is, on the contrary, yellow. This is the case with tobacco smoke and certain very fine precipitates, etc.

Even in a perfectly pure medium the particles of the medium itself result in some diffusion. This diffusion obviously follows Rayleigh's law as the molecules are extremely small compared with the wavelength of light. This is why a cloudless sky appears blue, the earth's atmosphere preferentially diffusing the short wavelengths. It is also a contributory factor in the redness of the sun at sunrise and sunset as under these conditions the atmospheric thickness which the light has to pass through is increased and this removes more of the shorter wavelengths (the phenomenon is in fact more complicated than this as the sun appears red and not the saturated yellow which this explanation would require). This is why the colour temperature of sunlight varies through the day. It is also the reason why a yellow filter, which absorbs the short wavelengths, can reduce atmospheric haze and to a greater degree why photographs taken with infra-red radiations of much longer wavelength, and consequently less prone to diffusion, enable distant scenes to be vividly recorded provided that the atmosphere is absolutely dry (water is a strong absorber of infra-red).

Interference phenomena The wave motion of light is used to explain the phenomenon of interference. If monochromatic light is projected from a narrow slit S, towards two parallel slits A and B in an opaque screen (Fig. 12) an image will be obtained on the screen E of alternate light and dark lines called *interference fringes*. This only occurs if the three slits A, B and S are sufficiently fine and if A and B are very close together. Each of the slits A and B emits, in effect, light waves,

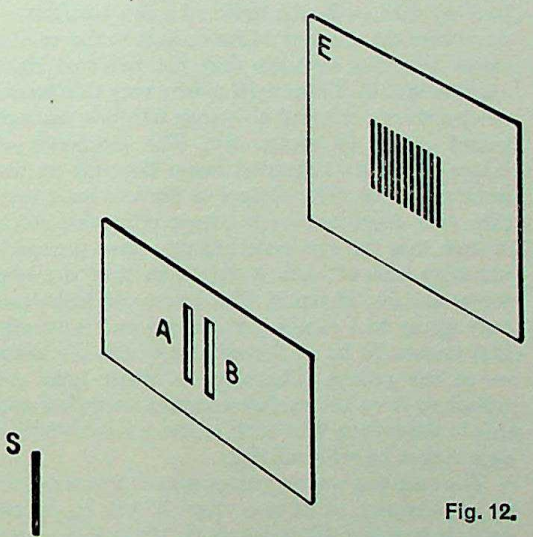


Fig. 12.

and where the two electric fields are in phase they are added together (that is at the point where the distance between the two slits differs by a whole number of wavelengths) whereas when they are out of phase they cancel each other out (that is where the distances between the two slits is an odd number of half wavelengths). The sum of two light beams can be zero, just like the sum of any two opposing movements. If the slit S emits white light the phenomenon is more complicated as at any point extinction of one wavelength occurs preferentially. Under these conditions the interference bands have colour fringes, on one side violet to green and on the other yellow to red,

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

alternately light and dark, covering the whole spectrum.

Likewise, consider a range of frequencies meeting a transparent layer, both surfaces of which reflect a certain proportion of incident light (Fig. 13).

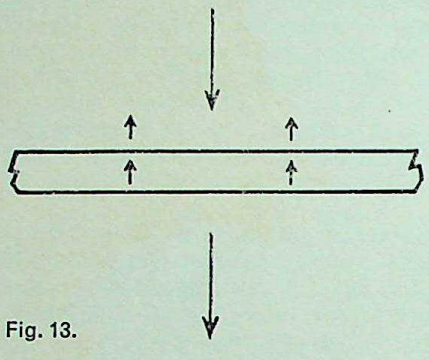


Fig. 13.

The reflected light waves will be in phase for certain frequencies and out of phase for others. The reflected light therefore varies in colour according to the thickness of the layer (this must be very thin — in the order of a few microns — otherwise the number of reflections in the visible range becomes so large that the reflected light appears white). This explains why very thin layers show a strong coloration — soap bubbles, films of petrol or oil on water, etc. The treatment of lenses to reduce reflection losses depends on the same principle. The surface of the lens has a very thin film deposited on it whose refractive index is such that the two reflected rays have the same intensity and of such a thickness that the two waves are out of phase. The latter condition can only apply to a single wavelength and generally it is chosen to be in the middle of the spectrum — in the yellow. Therefore in white light the reflection from the surface contains no yellow and this is the reason why such surfaces have a bluish appearance by reflected light.

The standing wave represents a particular aspect of interference. A known effect in the acoustical field, it is now applied to optics. Thus if a mirror is illuminated normally by monochromatic light, the incident and reflected waves interfere in front of the mirror and the result is at a maximum in a plane parallel to the mirror and at a distance of half a wavelength from it (Fig. 14).

If the mirror is covered with a photographic emulsion, the standing waves are formed in the latter and on development a series of partially reflecting planes of developed silver are formed, separated by a distance of $\lambda/2$. If under these conditions the plate is illuminated by white light at a normal angle of incidence, the reflections of wavelength λ are reflected by all the planes in phase and are added together whilst reflections of

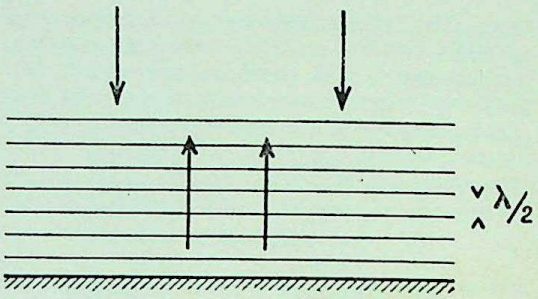
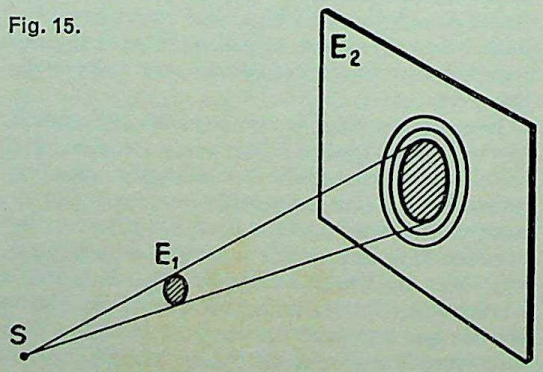


Fig. 14.

all other wavelengths are far less intense. In other words, when viewed by normally directed white light the plate reflects the radiations of the colours originally used to expose it. This was the basis of the old Lippmann process of colour photography which has now been abandoned in favour of more practical processes based upon the theory of three-colour vision.

Diffraction phenomena The wave motion of light also enables the phenomenon of diffraction to be explained. This occurs whenever light rays meet an obstacle and is easier to demonstrate than interference. If a small object E_1 is placed in front of a monochromatic point source S (Fig. 15), an image of the object in light and shadow is seen on a distant screen E_2 and, provided the point source S and the object E are sufficiently small, alternate light and dark bands will be seen at the junction of the lit and shaded areas. The explanation of these diffraction fringes is also due to the wave structure of light but is rather less obvious than the formation of interference fringes and demands a somewhat deeper study of the subject. Very simply, it can be said that light waves bend around the edge of any object just as radio or sound waves do. In all cases the phenomena only occur when the size of the object is of the order of a few dozen wavelengths; light waves can only bend round extremely small objects whilst radio and sound waves travel round much larger objects as their

Fig. 15.



CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Preservation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

wavelength is millions of times greater than that of visible light (the microwaves used in television are more susceptible to the presence of obstacles, as also are ultra-sonic waves).

When the dimensions of the object or of the opening are greater than a fraction of a millimetre, light waves are subject to no appreciable turning effect and it would appear that light is propagated in straight lines. This is the famous *principle of straight line propagation of light* which gives rise to the concept of light rays and to all geometrical optics; it is in fact only a first approximation which is usable when diffraction phenomena are negligible. Therefore if a screen pierced with an aperture O (having a diameter of about a millimetre) is placed in front of a point source S (Fig. 16) the straight line propagation of light principle indicates that a cone of light with its summit at S will be formed. But if the size of the hole O

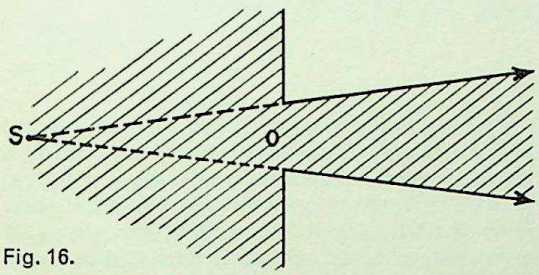


Fig. 16.

is decreased in order to isolate a single 'ray of light', diffraction phenomena become more and more marked so that the light emerging from the aperture O does so at a greater angle than the light entering it (Fig. 17).

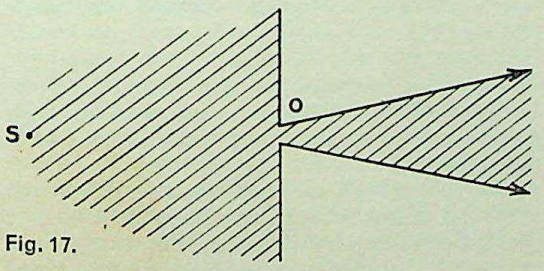


Fig. 17.

Diffraction phenomena also take place in optical instruments such as photographic lenses; the light waves are restricted by the diaphragm or more simply by the lens mount itself. Thus a perfect lens L forming an image A^1 of a point A (Fig. 18) does not in fact form a point image but a disc of light, which increases in size as the aperture of the lens decreases, surrounded by alternate light and dark fringes. It is these diffraction phenomena which limit the resolving power of microscopes, astronomical telescopes, spectroscopes, etc. With

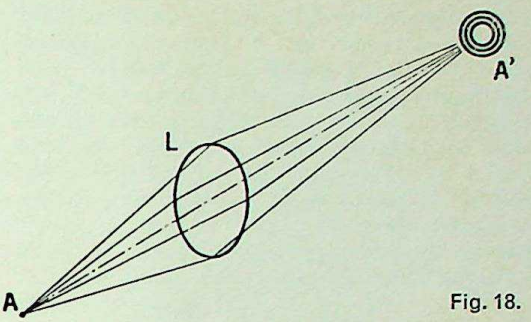


Fig. 18.

photographic lenses the effect is rarely noticed as the disc is small relative to emulsion irradiation (except in cases where the aperture is very small and the focal length considerable).

Polarized light The electro-magnetic nature of light waves enables the polarization of light to be explained. The electric field of an electro-magnetic wave is in fact 'transverse', that is perpendicular to the direction of propagation (Fig. 19). This is not a sufficient definition, for there are an infinite number of directions perpendicular to the direction of propagation.

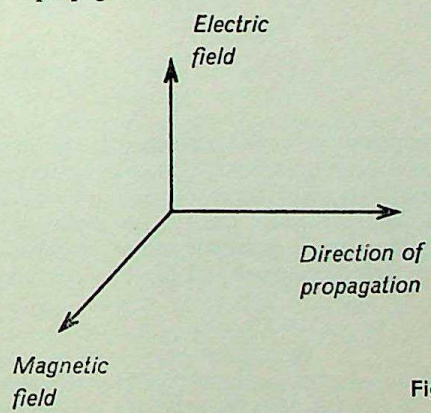


Fig. 19.

For all 'natural' light which has not been subject to any refraction or reflection, the orientation of the electric field varies at random 300 million times a second, and on average any light beam is effectively symmetrical in the make up of its electric field (Fig. 20).

Suppose apparatus is available to select a segment, only permitting a component $A\cos\alpha$ parallel to the selected direction to pass (Fig. 21). In this way 'polarized' light is obtained whose electric field has a fixed and defined direction (Fig. 22) and which no longer has a random field distribution but only two symmetrical planes, the one containing the electric field and the other normal to it (the latter is called the plane of polarization). The intensity of the light is proportional to the square of the intensity of the electric field; the intensity of natural incident light being

◀ WINTER LANDSCAPE — photograph by H. W. Gelbing using a Retina camera and Kodak Ektachrome film.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

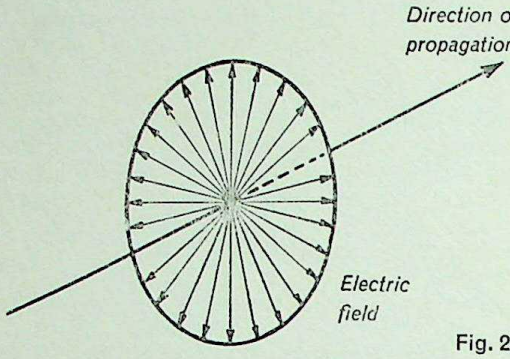


Fig. 20.

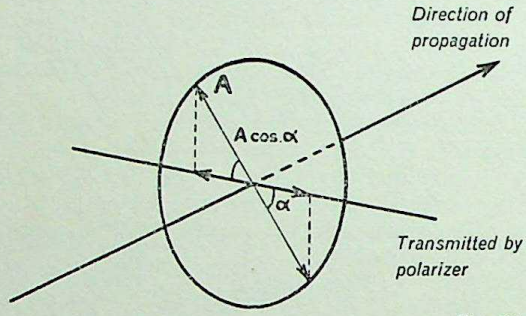


Fig. 21.

A^2, the polarized beam transmitted by the polarizer has a mean intensity of $A^2\cos^2\alpha$ (α varying at random 300 million times per second), which is $1/2A^2$. In other words, ignoring any losses due to absorption, etc, a polarizer transmits polarized light at half the intensity of the incident natural light.

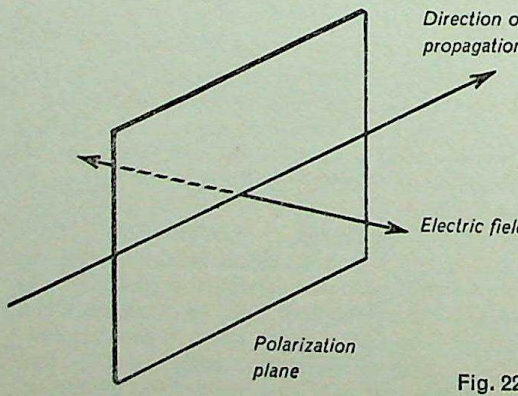


Fig. 22.

If the separation is not carried out perfectly the electric field parallel to a certain direction is merely transmitted preferentially (Fig. 23) and the light is only partially polarized. Such light can be considered as the sum of perfectly polarized light I_p, mixed with natural light of intensity I_n. The ratio

$$\frac{I_p}{I_p + I_n}$$

of the polarized light energy to the total light energy is called the polarization factor.

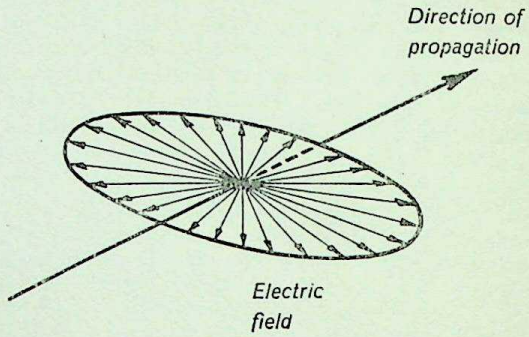


Fig. 23.

If a second polarizer, which for convenience will be referred to as an analyser, is placed in a beam of polarized light the analyser too will only transmit vibrations in a plane normal to the plane of polarization. It follows that if the planes of polarization of the polarizer and the analyser differ by α, the analyser will transmit an intensity of $I\cos^2\alpha$, I being the intensity transmitted by the polarizer. When the angle $\alpha = 90°$ the polarizers are said to be crossed and no light is transmitted. When $\alpha = 0$ the polarizers are said to be parallel and the light transmitted by the polarizer passes freely through the analyser. If the incident light is only partially polarized with a polarization factor of

$$\frac{I_p}{I_p + I_n}$$

the analyser transmits light energy of $I_p\cos^2\alpha + I_n/2$, which varies between $I_n/2$ and $I_n/2 + I_p$ according to the orientation of the analyser (but is never zero).

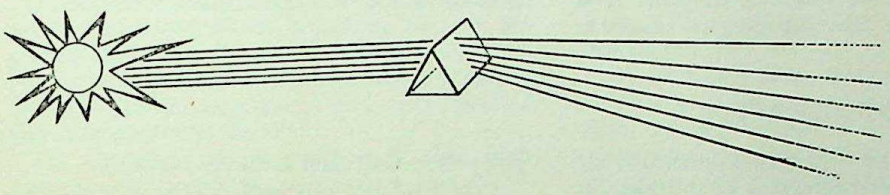
Certain crystals, such as Iceland Spar, have the property of polarizing almost completely without excessive absorption, but they are clumsy and expensive. In photography Polaroid layers are used almost exclusively, these consist of a plastic material containing minute crystals of quinone iodosulphate, which are uniformly oriented. As they are fairly strong light absorbers, polaroid screens have a light transmission relative to the incident natural light which is markedly below 0·5, frequently being as low as 0·25. Their use therefore necessitates a reduction of shutter speed or an opening of the iris diaphragm by about two stops.

Reflection and refraction both polarize natural light but the effect of reflection is far more pronounced. Polarization is almost complete when

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

reflection takes place at a greater angle of incidence than I_B, known as Brewster's angle, where $tgI_B = n_2/n_1$, n_1 and n_2 being the indices of the two media at the plane of separation where the reflection is produced (for air and glass I_B is about 57°). Thus the light reflected from the surface of the sea, or from a glass surface, may be greatly polarized, and consequently may be practically eliminated from the photographic point of view by a suitably oriented 'polaroid' filter.

Rayleigh scattering (that is diffusion by extremely small particles) also polarizes light, maximum polarization occurring in a direction at right angles to that of the beam of light which is diffused. Thus the blue light of the sky is partially polarized, the maximum polarization being perpendicular to the direction of the sun. A Polaroid filter can therefore reduce the effect of haze scatter in a way similar to that obtained with a yellow filter but with less colour distortion. Finally it may be mentioned that polarizing filters are used for stereo projection and viewing of colour photographs where obviously coloured filters could not be used.



M

MAKE-UP

Make-up for colour The make-up department in the professional cinema studio achieves fantastic results, some of which may be of use to the amateur photographer and cinematographer.

Tests with many colour processes show that perfect reproduction of skin tones is rarely achieved.

In professional cinematography make-up has been commonly practised in black-and-white work for many years in order to standardize to some extent the various skin colours. Contrasts between a pale and dark skin may not be very noticeable to the eye but when photographed together and presented on a large screen may produce too great a tone variation. Make-up also helps to mask small skin blemishes which seem to be magnified on the screen. In many cases characterization demands skin colour of a definite hue and here make-up must be used to achieve exactly the same colour day after day.

In this case the object is to obtain the most natural appearance on the screen.

With colour photography it is the skin tones which are the most difficult to reproduce correctly as they are made up of a mixture of relatively small quantities of all three image colours. The amount of red is the most critical.

Without make-up a man's face appears too red. In cases where all skin tones are similarly distorted a colour correction in the process to ameliorate the defect can frequently be introduced; usually the incorrent rendering is not general however. A suitable choice of foundation is the best way of correcting this fault.

The difficulty is that this foundation is absolutely indispensable in some cases but not in others. In other words each complexion requires individual treatment and it is a fallacy to believe that a single foundation can be used universally. If a single foundation is used such a thick layer must be applied that all trace of the natural complexion is lost. It is far better to use a range of foundations each of which will give the required appearance to a given complexion.

Another object of make-up is to provide continuity from the beginning to the end of a film although the natural complexion may vary slightly. An actress may for example start a film just after a holiday when she has a pronounced tan and this natural tan will have disappeared by the time the film is completed.

Ordinary street make-up has often been proposed for colour photography.

This is in fact true; studio make-up should be very much like normal street make-up as a completely natural impression is required.

But colour film does not have the same response the eye, and make-up which is to be used for as colour photography must therefore be subjected to numerous tests, both photographic and physical to ensure its suitability for the purpose.

Special products must therefore be used which have been designed for photography rather than general make-up use.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Make-up designed for back-and-white film use is obviously not suitable. Even though the eye may not notice anything wrong, its use may result in serious mistakes.

A few tests made with lipstick will illustrate this problem. In fact only very careful tests enable the right make-up to be chosen from its screen appearance; colours which are a match to the eye may appear different in the projected colour photograph owing to the different chemical constitution of the dyes.

Make-up for colour films is far more critical than for black-and-white, not only in the choice of make-up, but because of the far greater skill required in the make-up department. Colour must be delicately applied and barely perceptable to the eye; black-and-white film is far less critical and quite a different technique can be used. It is interesting to note that the progress made in colour make-up towards a more natural effect has been reflected in the black-and-white field by a similar tendency towards a more natural appearance.

Make-up can enhance the beauty of a film star's face or completely change the appearance to create a new character. But in this field the methods are more limited. The use of paste, masks, and false features in which certain make-up artists specialize, give a working foundation for black-and-white but are quite useless for colour. Colour film sees through the covering make-up and reveals the trickery underneath. Fresh methods must be used in this field.

To sum up, the use of make-up in colour photography is broadly the same as for black-and-white but the emphasis differs and new techniques have been devised to meet the different difficulties.

MARINE PHOTOGRAPHY

As far as colour photography is concerned the main characteristic of seascapes is the considerable amount of sky light and its reflection from the surface of the sea. Under midday conditions with a clear sky there is an unusually high proportion of ultra-violet present which is recorded by the film but not by the eye; even under less brilliant conditions the blue reflection from the surface of the sea is considerable.

This reflection will affect objects near the water; it is not the case however with objects reflecting light from the sun or the neighbouring sky and there is a great difference in colour between shadow and highlight areas. Ultra-violet absorbing filters such as the Wratten 1A are the most suitable for reducing this difference as their action is restricted to the ultra-violet; such filters require no increase in exposure.

An extremely blue sky may necessitate more correction: a pale yellow Wratten 81 filter can be used and this requires an increase in exposure of one-third of a stop.

If the sky is overcast a filter is less necessary (see Daylight), and its use may result in a slight yellow colour bias.

Early and late in the day, the excess of long wavelength light results in a predominance of warm tones to a greater extent than is realized. To reduce this effect a Wratten 82 filter can be used requiring an increase in exposure of one-third of a stop. Needless to say, a sunset whose main feature is the reddish glow of the sun, sky and reflections on any nearby objects should be photographed without filters.

Naturally if only the surface of the sea is seen it will appear extremely blue due to reflection of the sky; this can be corrected to some extent by a pale yellow filter such as the Kodak CC05Y.

Pure seascapes can prove rather monotonous; the introduction of another object can give some interest even though there is no other change in conditions.

A white surface, such as a sail, will add apparent contrast and intensity to the light.

Photographs of nearby objects, such as beaches with people in the foreground, require the same corrections as all other open air photographs, provided no special effect is sought, particularly in regard to excessive contrasts and colour reflections.

It must always be remembered that reversal films have a very short scale and that their contrast is designed for projection rather than for the production of paper prints. The softer gradation negative materials have appreciably greater exposure latitude and record a wider contrast range but the printing stage restricts the range of the negative which can be recorded and it is therefore only a case of giving greater exposure tolerance.

Exposure time In fine weather the high level of radiation, invisible as far as colour is concerned, prevents saturated colours from being obtained despite the inclusion of a white object to give the necessary contrast. The eye obeys the law calling for an arithmetical progression where the intensity follows a geometrical progression.

Similar contrasts, which may be of colour or brightness, are more apparent if the total intensity is low; the relatively low intensity image obtained by projection appears to be far more saturated than did the same sunlit scene. A projected slide which transmits most of the light received by it will give

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

an image of exaggerated brightness and faded colours. The greatest care must therefore be taken to avoid over-exposure which, however small, leads to a general loss of colour.

The exposure tables included with each film generally give quite a reliable guide and are of great use where identical conditions are encountered — time of day, sky condition, direction of sun — and where previous experience enables slight modifications to be made to the exposure calculations. A thoroughly standardized exposure meter is nevertheless desirable.

As the use of an exposure meter of the reflected light type tends to give an average density, the readings must be 'interpreted' (see Exposure) with high-key subjects receiving increased exposure and low key-ones decreased exposure.

By the sea where the subject is very open and where the sea and sky are important features, the general diffused light would lead to serious desaturation of colours if the usual extra exposure for light subjects were given. The meter reading should therefore be followed.

On the other hand a photograph taken from above showing the surface of the water but not the sky may appear too dark; a slight increase in exposure of about half a stop above the meter reading should put matters right.

Middle distance objects, rocks, boats, etc, often result in excessive contrast, not only of colour but also of brightness. Little can be done but accept this and no attempt should be made to lighten shadows, unless they occupy the middle of the picture and are really the centre of interest. It is always important to try to obtain the best colour reproduction in light colours wherever they are.

Critical experiments should include a well-lit white surface and the best image will show, for example, the minor variations produced by a slight curvature. The reading obtained from the white surface with the exposure meter will be reliable as only light reflected from this surface will enter the cell; a measurement made close to the white surface and including nothing else requires an increase in the calculated exposure (see Exposure).

Some reversal films cannot tolerate more than half a stop under- or over-exposure and great care must therefore be taken to standardize exposure meter readings and conditions. By the sea, however, it is over-exposure which must be particularly avoided.

MASKS

Colour rendering In the section on subtractive processes it is shown that for several reasons perfect results are possible only in theory.

1. The spectral sensitivities of practical emulsions are not identical with those required by the colorimetric laws (see Colorimetry).
2. The photographic characteristics of an emulsion are not necessarily ideal either in straightness of the characteristic curve or in the conformity of the three curves making up a tripack material.
3. The amount of dye formed in the photographic layer is not entirely dependent upon the exposure received by a particular layer; inter-action between the various layers during development can effect the amount of dye produced in any one layer (inter-image or vertical Eberhard effect).
4. The overall contrast of a reversal system is not unity; to increase colour saturation it is usual to increase the overall contrast considerably.
5. The spectral characteristics of the photographically produced image dyes are only an approximation to the ideal requirements of a three-colour subtractive process; this is perhaps the most important factor of all (see Fig. 1).

Each practical dye has a principal absorption region: red for cyan dyes, green for magenta and blue for yellow dyes, together with an unwanted absorption band usually in the blue and green for cyan dyes, which tend to degrade the resulting colours.

Compared with the original colours, those pro-

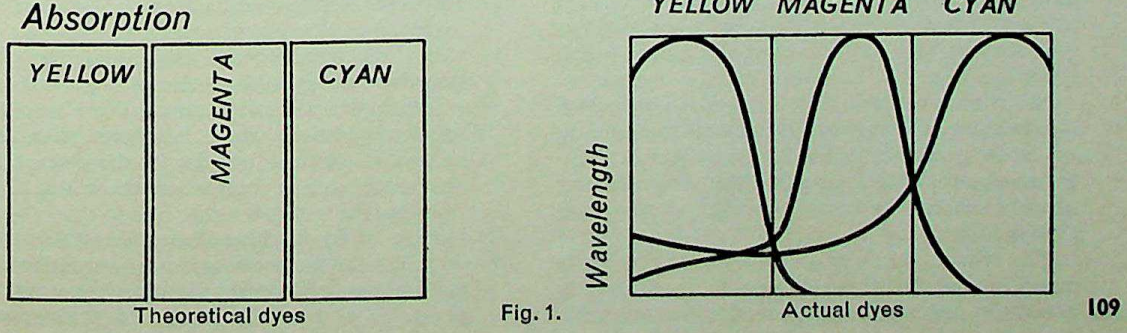


Fig. 1.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

duced in the resulting photograph show a colour change and loss of brilliance.

The differences in sensitivity together with the inaccuracies of the image dyes tend to desaturate and darken colours; in practice greens and blues are considerably darkened. The lack of conformity between the three image curves leads to a lack of colour balance which varies with the density.

Finally the inter-image effects can in certain cases prove beneficial whilst the overall contrast increase compensates for the unavoidable loss of brilliance.

At the present time there is no precise theory which takes into account all the factors effecting colour reproduction, starting with the camera film, the photometric characteristics of the dyes, and the shape and mutual inter-action of the individual sensitometric curves.

The calculations which have so far been made are for particular cases and translate into figures the losses in both brightness and accuracy. The main reason for these losses is in the nature of the subtractive dyes. The expression of these losses is straightforward and not particularly elaborate in the case of reversal processes where only one dyestuff system comes into play (see Kodachrome, Agfacolor, etc).

This is not so, however, with negative-positive processes, where two dyestuff systems are in use. In these cases there may be sufficient experimental error to make the results suspect.

The same argument applies in the case of duplicating; for example making Kodachrome duplicates from Kodachrome originals.

It is possible to eliminate many of the deficiencies in colour rendering by the use of a technique known as masking.

Definition of a mask. The name mask is given to any black-and-white or colour derivative made from a subtractive colour negative or positive whose object is to correct tone or colour rendering.

Theoretical use of mask A simple example will illustrate the use of a mask. Let us assume that our reproduction system is based on general theoretical principles but that the spectral absorption of the dyes follows practical limitations: that is the yellow dye absorbs green light, the magenta dye absorbs blue and the cyan dye absorbs both green and blue.

What takes place is that wherever there is cyan dye in the image, it controls not only the amount of red light present in the incident light but also the amount of blue and green light, thus behaving to some extent like a magenta and yellow image also (see Fig. 2).

The amount of magenta and yellow dye must therefore be decreased wherever cyan dye is present in order to compensate for this apparent

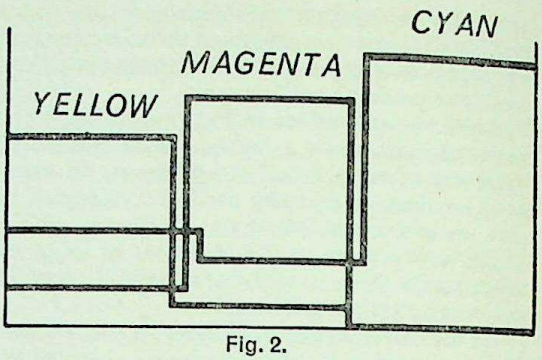


Fig. 2.

presence of yellow and magenta dye caused by the unwanted absorption of the cyan dye.

In practice, the control of an image dye stuff in proportion to the quantity of the other two image dyestuffs presents the problem of producing either an interaction between the images to give the desired result, or an adjustment of the amount of one dye relative to that of the other two when the final image is obtained via a printing stage, as for example in any processes starting off with direct separation negatives or using separation negatives as an intermediate step:

three colour separation → Dye Transfer

Transparency → three colour separation → Dye Transfer,

finally, in negative-positive and all duplicating systems.

For reversal processes the only method is to control the inter-image effect. In cases where a printing stage is involved the following procedure can be used.

Take three separation negatives prepared for printing with perfect dyestuffs. With a method such as the carbon process in mind for obtaining the final image with the dyes shown in Fig. 1, the separations are modified as follows:

(*a*) Correction for the unwanted absorption of the cyan image in green light. As the ratio of the unwanted absorption in green light to the principal absorption in red light is 30 per cent, a positive is made of the red separation negative whose contrast is 30 per cent of that of the negative. This positive is registered with the magenta negative and gives a green-light separation (masked or corrected), see Fig. 3, where the sensitometric data concerning the negative and the mask are shown.

When the positive is printed, the masked green separation, which is denser than the original separation, results in the formation of less magenta in areas where there is to be a cyan image.

(*b*) Correction for the blue absorption of the cyan dye: by similar reasoning it can be seen that as the blue absorption of the cyan dye corresponds to 35 per cent of its red absorption,

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

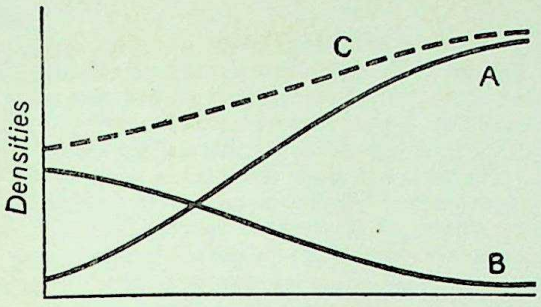


Fig. 3.
A. Magenta separation. B. Mask.
C. Magenta separation plus 30% cyan mask.

a positive made from the red separation and, developed to a contrast of 35 per cent of the latter will, when registered with the blue negative, reduce the amount of yellow in areas where there is to be a cyan image and thus correct for the unwanted absorption of this image.

Working in this way, two masks will finally be made from the red record at 30 per cent and 35 per cent: the 30 per cent one is registered with the green record whilst the 35 per cent one is registered with the blue record; a 25 per cent mask is made from the green filter negative and is registered with the blue filter negative whilst from the blue separation negative a 20 per cent mask is made and registered with the green filter negative.

To sum up, the correction of the four unwanted absorptions of the selected pigment system is carried out by means of four masks which are registered with the separation negatives. The process is obviously only possible when used together with a build-up type of print process, such as Carbro, used in this example.

Practical use of masks Considerable practical use is made of masking in the photogravure and other photomechanical processes; the problem of imperfections is far greater with printing inks than with photographic dyes. It is, however, essential to control most carefully the production of the masks for slight errors could easily become great owing to the large number of printing stages involved. The use of masking for photogravure was discovered empirically by Albert in 1898.

In practical colour photography the number of masks which can be used is far smaller than is required by the theoretical considerations already discussed. The cyan dye almost invariably requires correction and is frequently the first image to be masked.

Magenta dyes always have particularly high blue absorption whose correction requires a mask. The red absorption of magenta dyes and the red and green absorption of yellow dyes are generally low enough to be ignored.

(a) Use of masks in processes where separation negatives are used In this case the procedure is exactly as for the theoretical example but with the number of masks restricted as described above. The corrections are made simply on the basis of the dyes or pigments used for the final image.

(b) Use of masks when a colour original is used (Example: Kodachrome or Ektachrome original to dye transfer print) — Two dye systems take part in this type of procedure:

1. those of the original (Kodachrome, Ektachrome) which have unwanted absorptions,
2. and those of the reproduction (Dye Transfer).

The masks which are used should in theory compensate for the unwanted absorptions introduced by both systems. In fact in this particular example it is generally sufficient to correct only for the faults of the original transparency as the dyes used for the final reproduction are extremely accurate in their absorptions.

In the scene:

A	B	C
Original transparency (Kodachrome, Ektachrome)	→ black-and-white separations	→ Dye Transfer

The original colour transparency A takes the place of the colour original for obtaining the three colour separations and the original subject is only seen via this transparency which has already suffered some degradation.

It can be readily seen that in the preparation of the three-colour separations, errors will occur because of this. With a colour original it is not a case of mechanically separating three layers to enable the three separation images to be individually printed. The integral nature of the tripack makes it essential to print the three images using red, green and blue light of definite composition to give the maximum possible separation of layers when the three negatives are printed.

Even under the best possible conditions the negative of the magenta image is contaminated with a lower contrast but quite definite image of the cyan; the blue filter negative gives not only an image of the yellow but also a low contrast image of the magenta and cyan, etc. This is the reason for masking.

The procedure is as follows:

Kodachrome

The red filter negative is made direct through a Wratten No. 29 filter.

The green separation is made using a Wratten No. 61 filter and before the separation is made the transparency is registered with a 33 per cent negative mask.

The blue filter positive is made using a Wratten No. 49 + 2B, together with two masks — the 33

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

per cent red filter mask and a 33 per cent green filter mask, both bound up with the transparency.

In practice masking is frequently simplified to the extent of merely correcting the imperfections of the cyan dye; a negative made from the transparency using a Wratten No. 29 (narrow cut red) filter is bound up with the transparency before the separations are made. It is readily seen that in theory this method is the equivalent for the blue and green separations of the method given above.

On the other hand, the preparation of the red separation from the transparency masked in this way merely reduces the contrast of the separation negative (with no other unwanted effects). This contrast loss is compensated by an increase in the development gamma of the separation.

Ektachrome

The general procedure is the same as the simplified Kodachrome procedure with the exception that two masks must be prepared, one through the red Wratten No. 29 filter and the other through green Wratten No. 11; the mask made through the red filter is registered with the transparency when making the red separation using Wratten No. 72A and when making the green separation using Wratten No. 61; for the blue light separation (Wratten 35 + 38A filters) both the red filter mask and the green filter mask are used in register with the transparency.

(c) Use of masking when copying Kodachrome on to Kodachrome The problems are substantially the same as those already dealt with except that an effort must be made to correct for deficiencies in both the original and the copy.

The basic technique remains the same as that of the simplest cases above, i.e. a single silver mask made through a Wratten No. 29 filter. The process is virtually restricted to the use of one mask owing to the integral nature of both original and copy. The use of a single mask enables a one-stage white light printing process to be used.

The arguments which have already been put forward regarding the choice of filters in the preparation of separation negatives indicate that improved results would be obtained in white light copying if the white light consists of a mixture of blue, green and red light. In each case the maximum energy of the light should be at the same wavelength as the maximum absorption of the particular dye (see Additive printing on page 116).

Alternatively the sensitization maxima of the three layers of the duplicating film may correspond to the absorption maxima of the three dyes of the original. The combination of white light together with steep spectral sensitivity bands ensures maximum separation.

MEDICAL AND SCIENTIFIC COLOUR PHOTOGRAPHY

Colour photography plays an important part in medical science. It can be readily seen that black-and-white greatly limits the scope of photography by restricting the image to a range of greys. Colour photography may also be much easier to carry out as well as giving more satisfactory results than black-and-white work. This is especially noticeable with such branches as bronchial endoscopy or the photography of variously-coloured skin lesions. The reproduction of the colour and also the relief of the subject results in a very satisfactory impression when a slide is projected. Colour photomicrography is also of great value as an auxiliary to hystology, cytology, microbiology.

It is obviously a great advantage with a large audience of students or even of specialists to be able to project colour photomicrographs which have been prepared under the most ideal conditions and of phenomena which may be relatively rare. It is far more difficult and laborious to use even the most modern and powerful projection microscopes whose light sources, from the point of view of colour, are as yet far from perfect. Even with the most advanced equipment the lecturer must to some extent ignore his audience when occupied with the critical operation of the instrument. Even if a satisfactory method of dealing with an immersion objective is available, there is still the problem of exploring the slide a little at a time until the area of particular interest is found. This difficulty becomes of major importance when very high magnification is involved. Under these conditions it is much better to produce beforehand an adequate number of colour photomicrographs which can be quickly and conveniently projected on the screen during the lecture without interruption and without creating a distraction to either lecturer or audience.

Some photomicrographs are most easily made on 35 mm. film. A set of 24 × 36 mm. slides occupies the minimum of space and is light in weight; furthermore, reasonable quality duplicates with only small colour losses can be made by film manufacturers or specialized laboratories.

This size is also preferred for most medical documentation work — pathological and surgical photography, photography of internal organs, photomicrography.

All processes can give good results provided the operator is familiar with the one in use. The best photographs will be obtained when the operator

LONG-EARED OWL — photograph by H. Stern using flash and Kodachrome film with a Retina camera. ▶

CC-[illegible]nigam[illegible]gital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

is so familiar with his equipment that the technicalities require no thought and he can devote himself entirely to the illustration of the particular point of interest.

Two technical points in particular require attention:

1. The determination of exposure.
2. The control of the light source.

In photomicrography the exposure meter is more frequently used for control than for actual measurement. Preliminary tests with the equipment — lamp, filter, condenser, various objectives, eyepieces — are used to determine the correct exposure for several typical subjects. The intensity of light emerging from the eyepiece is then standardized by using the meter at a fixed distance from the exit pupil. In the final photograph the exposure meter enables the operator to refer back to successful photographs of a similar type. Some of the difficulties can be removed by using electronic flash, which can be used in conjunction with the normal lighting which at quite a low level is used for visual adjustment and for control. The latter does not by itself produce any photographic effect during exposure. Electronic flash together with suitable correction filters (Kodak CC10Y and CC10R) is used with daylight type colour film. It is quite convenient to use part of the 20- or 36-exposure roll for photomicrography and the remainder for other clinical work in daylight. The use of flash with exposures in the order of 1/1000 sec. makes it possible to use temporary microscope mounting without risk of movement.

Electronic flash also enables excellent colour photographs of teguments, organs, lesions, to be readily taken under well controlled conditions.

Note: other light sources near the subject, tungsten or fluorescent lamps, can interfere with the electronic flash lighting and give incorrect colour rendering. Care should be taken to avoid strong coloured reflections from the room walls; sick rooms may be painted blue, green or yellow and a nearby wall of such a colour could introduce a colour cast. The subject should therefore be surrounded with black or white screens which may be either glossy or matt so that the light distribution can be controlled and its colour will remain constant from highlights to shadow. Overcoming these difficulties is the most personal and fascinating aspect of this type of photography.

MISCELLANEOUS (Colour)

Colour photographs in which the colours are purely representational can give most interesting results in certain cases. They can also give artistic or spectacular effects when used with imagination. Several examples are given.

'Colour photography' of the invisible It is possible to extend the perception of the eye into the near infra-red and near ultra-violet by using colour film differentially sensitized to these regions. For this the three sensitized regions would be the normal visible band, the infra-red and the ultra-violet. The ultra-violet aspect is rendered in blue-violet, the visible band in green and the infra-red in red.

By using a process such as Dye Transfer or by toning, separate coloured positive images can be superimposed to give the effect of a greatly extended visible range.

Aerial photography In the section on aerial photography the use of emulsions giving arbitrary colouring was discussed in connection with certain topographical work and for work in which one particular colour is used to represent infra-red (to indicate camouflage for example).

Oscillograms To separate a number of simultaneous cathode ray oscillograph traces or to compare successive traces, recording can be carried out on colour film using arbitrarily chosen colours for the different events. A white screen cathode ray tube is used for each trace with the interposition of a different coloured filter for each trace. In this way one has curves in red, green, blue, and so forth.

This process can also be used for the production of photo 'abstracts', by utilizing suitably shaped traces in different colours. The method is far more certain and predictable than the use of a swinging light source.

Fluography Using the methods described below it is possible to obtain fluorescent photographs in various colours (see Fluorescence). For example in metallurgy, fluography is sometimes carried out in several stages.

1. The sample is treated with a solution of a fluorescent substance, dried and examined and and photographed by ultra-violet radiation. This shows up any cracks and fissures.
2. The sample is sprinkled with an absorbing material and photographed after 15, 30 and 60 minutes; this provides information on the depth and volume of the fissures from the extent of the fluorescent patches around the cracks.

By using a fluorescent material having a wide emission band or several fluorescent salts dissolved together and by taking successive photographs through coloured filters, a valuable and easily interpreted record of the various stages is readily obtained.

◀ LATE AFTERNOON — photograph by H. W. Gelbing using Kodachrome film with an exposure of $\frac{1}{30}$ sec. *f*/5·6.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

MOUNTAIN PHOTOGRAPHY

Mountain scenery can exhibit very high brightness and very high contrast. In fine weather the clear atmosphere results in very bright conditions whilst the numerous opposed and deeply coloured planes result in a wide contrast range. The sky and the peaks may be brilliant whereas the valley may be in deep shade.

The lighting contrast range of 4:1 is frequently exceeded but there is little purpose in worrying about exaggerating an unavoidable defect.

The important points to watch are the reproduction both in brilliance and colour of the highlights and the avoidance of the bluish shadows which are predominantly lit by the sky.

For the latter purpose an ultra-violet absorbing filter can be a permanent fixture on the lens together with a lens hood.

In current landscape photography, foreground and middle distance objects are of prime importance with the far distance serving mainly as a background to lend perspective to the composition.

With mountain photography, on the other hand, it is the distant parts which comprise most if not the whole of the subject; a relatively unimportant foreground object may give scale and by opposition of colour and contrast give a strong relief effect.

This relief effect must be strongly marked as the essential sharpness over a great depth of field is not conducive to a sense of perspective.

The same conditions apply for a colour photograph as for a black-and-white one — composition, placing of figures and interpretation of the subject.

The high contrast of back-lit subjects appears to contradict the basic principle of colour photography which is to obtain colour contrasts rather than lighting contrasts. The presence of underexposed rocks or trees, silhouetted in the foreground, serves to accentuate the main background subject area which must be correctly exposed. This brings us back to the method of exposure based upon highlights.

Care must be taken to locate the dark areas as far as possible in the foreground; strong contrasts at several different points in the image should be avoided. In most cases these contrasty effects are not the most colourful or show such a wide range of colours that only a material with the latitude of black-and-white film could record them: for example, a waterfall seen through trees.

In mountain photography, back-lit effects are not solely produced when the sun is facing the photographer; many are produced in the shadow of a large obstacle with a brilliantly lit surface as the effective light source. One example, primarily of interest to the black-and-white photographer, is figures in the snow with the sun near the horizon. In this case the movement of the people compensates for the lack of detail in the silhouette. Close-ups in sunlight should have synchro flash fill-in (see Children).

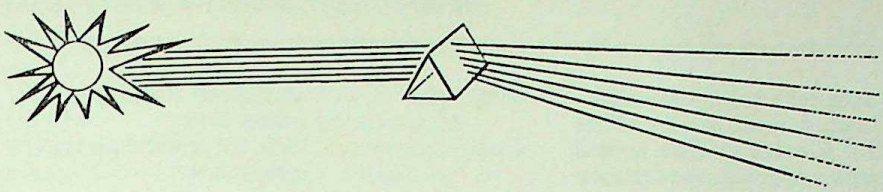
A more frequently occurring case is that of steeply sloping areas situated in shadow which stand out from their surroundings due to their general higher level of illumination and in fact constitute the main subject: they must be given the most important position in the photograph and should be used as the basis for the exposure, ignoring the areas in deeper shadow.

These are far from colourless in the final picture but are frequently rendered too blue, especially when the atmosphere is clear; a Wratten 81 filter is often useful to overcome this colour cast. Generally for daylight work it is best to use daylight type stock; however, for mountain photography, tungsten type sticks give excellent results when used with a suitable correction filter. Colours may be rendered a little on the warm side but ultra-violet radiation has little effect on the emulsion and distant scenes are recorded with maximum sharpness and detail.

The filters for use with the various tungsten type stock are:

3,400°K	Type A	Wratten 85
3,200°K	Type B	Wratten 85B
3,800°K	Type F	Wratten 85C

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



N

NEGATIVE-POSITIVE PRINTING

General Whilst in the printing of black-and-white positives from negatives only two factors must be taken into account — the exposure and the selection of a paper of suitable contrast, colour printing introduces a further critical factor — colour balance. For various reasons the print produced from a colour negative may have a colour cast which is readily perceived by the eye. Such colour casts may be due to defects in the negative or positive materials themselves, processing errors or to exposure under incorrect lighting conditions, and to produce satisfactory prints filtration must be carried out with great care.

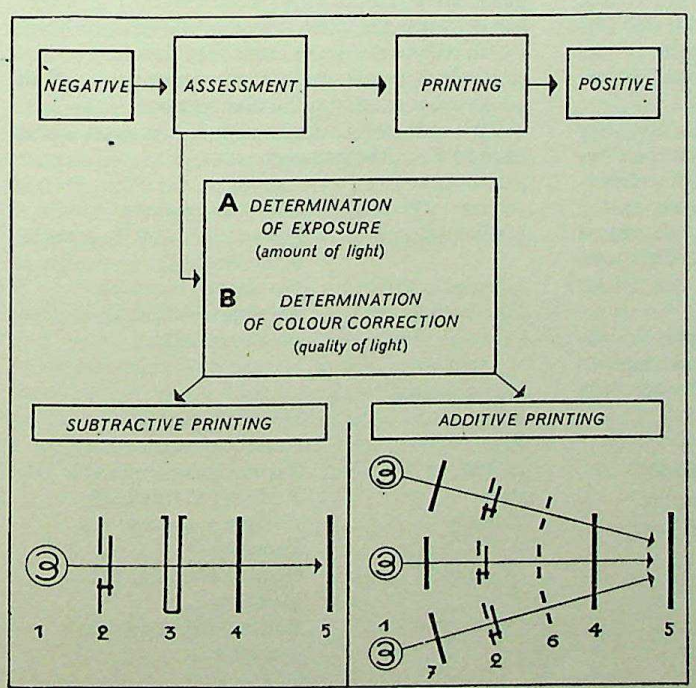
In principle these colour casts are due to a predominance of one or two of the individual cyan, magenta or yellow colour images. This means that the cast will be either yellow, magenta or cyan or a mixture of any two of these — blue, green or red. For this reason colour printing filters are different densities of yellow, magenta or cyan, and may also include a similar range of blue, green and red filters, i.e. the Kodak Colour Compensating Filters for use with Ektacolor Print Paper.

In practice grading involves the determination of the following factors:

(*a*) The correct quantity of light achieved by adjusting either the intensity or the exposure time.

(*b*) The quality of the light by either introducing complementary filters to modify white light in the case of subtractive printing or by adjusting the ratio of red, green and blue light in the case of additive printing (Fig. 1).

Due to the difficulty in assessing the quality of a complementary colour negative by straightfor-



1. Light source. — 2. Shutter. — 3. Filter holder. — 4. Negative. — 5. Positive paper. — 6. Diaphragm. — 7. Blue, green, red, additive filters.

Fig. 1.

Subtractive printing:
The exposure is made in one operation after adjusting the quality of the light and exposure time.

Additive printing:
Exposures are made through red, green and blue filters in succession, the aperture is separately adjusted for each of the 3 exposures.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

ward visual means, automatic colour assessment methods should be used as far as possible. With motion picture work it is usual to make several copies of the same scene using different filtration applied to successive frames. Such a method is possible when a large number of final copies are required. In the case of paper prints, however, only one copy is required in the majority of cases and for the laboratory to run economically, the first print should be correct. The method of assessing the colour negative quality in paper printing depends on the printing method used — additive or subtractive. These two systems will be compared before actually dealing with the grading methods.

Subtractive printing (Fig. 1) In this method the following adjustments must be made.

1. Quantity of light by adjusting time or intensity.
2. Quality of light by inserting complementary coloured filters in the light beam.

Let us consider the case of an under-exposed negative (low density) having a green cast visible on objects which are obviously neutral grey. If this negative is printed in the same way as a correctly exposed and balanced one, the resulting print will be too dense and will have a magenta cast. It is easy to see why the low density negative results in an over-dense print.

In the case of the colour cast, the negative being predominantly green will transmit more green light than would a correctly balanced negative and this excess of green light will over-expose the green-sensitive layer of the paper and produce an excess of magenta dye.

To print this under-exposed negative correctly therefore, the total amount of light must be reduced as in black-and-white work and the deficient magenta layer giving the green cast to the negative must be compensated by adding a magenta filter of appropriate density. This correction filter is of the same colour as the colour cast of the first test.

The general exposure level must again be adjusted to compensate for the additional magenta density which has been added. The following chart serves as a rough guide.

Defect	*Correction required*
Light negative	Reduce exposure time
Normal negative	Normal exposure time
Dense negative	Increase exposure time
Negative cast	
None	Normal printing
Blue	Add yellow filter
Green	Add magenta filter
Red	Add cyan filter
Yellow	Add blue or add magenta plus cyan
Magenta	Add green or add cyan plus yellow
Cyan	Add red or add magenta plus yellow

As it is usually easier to assess the negative characterisitics after making a preliminary test, the following table shows the corrections required based upon the characteristics of the first test.

Positive cast	*Correction required*
Yellow	Add yellow filter
Magenta	Add magenta filter
Cyan	Add cyan filter
Blue	Add blue or add magenta plus cyan
Green	Add green or add cyan plus yellow
Red	Add red or add magenta plus yellow

Additive printing (Fig. 1)

The adjustment is carried out by varying either the intensity or exposure time for each of the three primary light beams used in printing. To avoid reciprocity effects it is preferable to adjust the light intensity. Using the same example of a low density negative with a magenta cast that was used for subtractive printing, a normal additive print using intensities I_1, I_2, I_3 of blue, green and red light will similarly produce a dense magenta print. A correct print is obtained by:

(*a*) reducing the intensity of all three light beams to reduce the overall intensity and

(*b*) reducing still further the intensity I_2 of the green beam to reduce the magenta cast.

The following chart shows the corrections needed for different cases.

Defect	*Correction required*
Light negative	Reduce all three intensities proportionally
Normal negative	No change required
Dense negative	Increase all three intensities proportionally
Negative cast	
None	Normal printing
Blue	Reduce blue intensity
Green	Reduce green intensity
Red	Reduce red intensity
Yellow	Reduce green and red intensity
Magenta	Reduce blue and red intensity
Cyan	Reduce red and green intensity

The following table gives the corrections necessary for casts in the trial positive print.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Yellow	Reduce blue intensity
Magenta	Reduce green intensity
Cyan	Reduce red intensity
Blue	Reduce green and red intensity
Green	Reduce red and blue intensity
Red	Reduce blue and green intensity

From the colour balance point of view the same effect will be achieved by reducing one primary beam as by increasing the other two. In practice there is no alternative as the requirements of density correction will decide which method is in fact used.

The additive system of printing has certain advantages over the subtractive method, one of which is the ability to carry out the printing operation by exposing only one layer of the positive film at a time and correcting each independently. This is not possible with the subtractive system owing to the unwanted absorptions of the correction filters. The additive method is, however, much slower as each completed print involves an exposure in three stages.

Principles of grading When discussing the additive and subtractive systems the use of a normal negative was mentioned. This is a negative which will print correctly under the ideal conditions laid down by the manufacturer. The use of a reference negative is extremely important in all the grading methods. Once the printing conditions for this standard negative have been determined by making successive tests until the correct reproduction is obtained, this negative is used as a guide with which the negative to be printed is compared and the difference estimated. This comparison method has now generally superceded the empirical method in the production of mass-produced paper prints.

A. Empirical method In this method several tests are printed from the negative using different filter combinations so that after processing the most satisfactory filters can be determined by examining the test print. The different filter combinations used in the tests must be selected so that the required pack falls within their limits. This method is, of course, very simple and reliable but care must be taken to maintain the same conditions for both test and final print. The method also involves the waste of an appreciable amount of printing material. For high quality professional work, particularly where large-sized prints are made, the method is invaluable but it is far too expensive to be used for amateur colour developing and printing. For use with this method a filter mosaic, the Colorax, has been marketed by Agfa for use with the Agfacolor system. Up to seventy-two different filter combinations can be used.

B. Standard negative method As we have seen, the method involves establishing the conditions necessary for correctly printing a typical negative and then using this negative as a basis for comparison with the negatives which are to be printed. The 'unknown' negative is compared with the standard and the difference between the two is estimated in terms of the correction which the 'unknown' negative will require. The methods used by various printing laboratories differ in the way that the differences between the standard and the unknown are estimated. The only measurements which can be made accurately on a negative are the red, green and blue filter densities at any given point. This information can be obtained simultaneously or successively. For example: the negative can be examined with a densitometer — either visual or photo-electric — to determine the lightest or densest areas (Fig. 2).

The two arrows show how the negative is moved about to examine it point by point. This method will give an indication of the effective contrast of the negative as well as the exposure time for the highlights which is determined by measuring the dense areas of the negative. In the USA a similar system is used for automatic printing of black-and-white negatives using a variable contrast paper. Papers such as Varigam or multigrade can produce a difference in contrast according to the colour in exposure light. A photocell is used to measure the contrast of the negative and this information is used to control the colour of the light and at the same time the exposure duration is altered according to the density of the negative.

Such automatic printing methods can be used for mass production of prints and give a very high

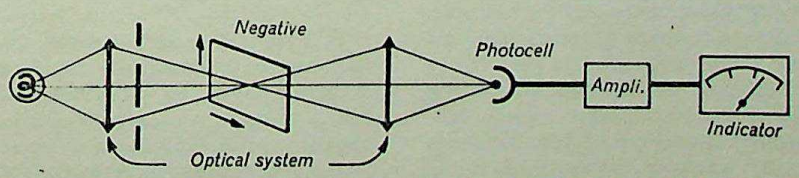


Fig. 2. — The two arrows show the way the negative is moved to measure it point by point.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

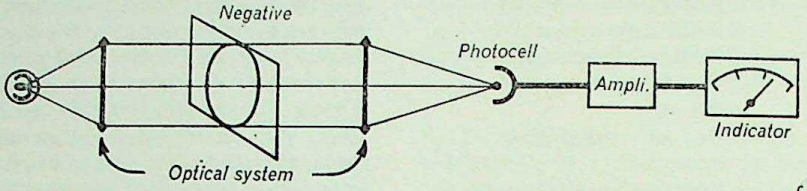


Fig. 3. — The use of red, green or blue filters in the light beam enables colour densities to be measured.

proportion of acceptable first prints; the reject rate is usually only a very small percentage.

Variations in contrast cannot be compensated when adapting this method for colour printing as most colour papers are available in only one grade. The average density of the negative can be determined by reading the whole negative or a very large part of it with what is in effect a large area densitometer. This method of integrating the overall density is used successfully in most countries for the production of black-and-white paper prints on a single grade of paper. The grade of paper used is the most suitable one for the majority of subjects encountered in amateur developing and printing work. The method has been adapted for the automatic production of colour prints.

The general system is illustrated in Fig. 3.

By using red, green and blue filters in the light beam, colour negative densities are measured. If the complete negative area cannot be readily measured the portions selected should be in the centre of the field which usually corresponds to the subject's main interest point. A standard negative is first measured giving readings Bs, Gs and Rs. The negative to be printed is then measured giving readings of B, G, R. The differences between Bs and B, Gs and G, and Rs and R, are used to calculate the exposure of the unknown negative. The commercially available apparatus for automatic grading will be described later. This method gives good results provided the standard negative is of the same general type as the negatives which are to be printed. More precisely the method is satisfactory as long as the readings B, G and R do not differ from the standard Bs, Gs and Rs by amounts greater than those encountered in practice due to variations in manufacture, exposure or processing of a given negative material. On the other hand the system of integrating the negative characteristics to produce a standard print will break down in the case of subjects of unusual density or colour character; for example, a photograph of a white cat in the snow will produce a balanced neutral negative but this will be 'corrected' in printing to an average density giving a picture of a grey cat against a grey background. Any subject having a relatively large area of one colour, for example, a cornfield, a red brick wall, grass, blue sky, etc, will result in an incorrect compensation if the density readings are applied automatically. The negative of a lawn for example, which will be predominantly magenta, will be printed to give a print having an excess of magenta. Similarly if a portrait is taken with a large area of red brick background the tendency will be to 'correct' for the red brick predominance and give a subject with excess cyan in the features.

The following points must be taken into consideration when using this system:

1. The standard negatives should be chosen so that it represents as far as possible the negatives to be printed.
2. Any subject error caused by an unusual predominance of one colour must be eliminated by visual assessment and application of a suitable correction. This is largely a matter of experience and training.

In short, the integrated density and colour method of grading colour negatives is not perfect due to the lack of standardization of subjects, but it is the only method which has so far been devised by which a large number of amateur colour negatives can be acceptably printed at a reasonable price.

Grading equipment Some grading equipment is independent of the printing equipment and the reading obtained must be converted into printing terms and applied manually to the printing system. In other cases the grading system forms an integral part of the printer and the readings are converted to printer corrections which are automatically applied. Among the separate grading instruments are:

A. The Homrich visual comparator This is a three-colour photometer having a comparison area corresponding to a standard negative. The negative to be graded is placed in the appropriate position and balanced to match the standard by means of filters. These are then used to indicate the corrections required during printing.

B. Lize's Correcto meter In this apparatus the negative is placed in a carrier where it can be illuminated with red, green or blue light. A photocell is fitted into a cover which hinges over the negative and is held down to make the measurements. The output from the cell is measured by means of a galvonometer which has previously

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

been calibrated with reference to a standard negative. The galvanometer reading is brought to the standard position each time a reading is made by adjusting a diaphragm in the path of the light beam. The information obtained can be used directly when printing by the additive filter method or, by using conversion tables, the requisite complementary filters can be calculated.

PRINTING EQUIPMENT

A. Printers without grading facility These correspond in principle to those illustrated in Figs. 1 and 2; one being suitable for additive printing and the other for subtractive printing. The light source must be suitably standardized. When large quantities of amateur prints are made, prints are made on rolls of paper carried in cassettes which automatically advance the material after each exposure. The method used for adjusting the correction filters is either to use a filter drawer into which suitable filters are inserted or to use a more easily adjustable unit such as the Agfa Varioscope.

Agfa Varioscope This is an enlarger head unit comprising a lamp, a complementary filter set and a suitable optical system. Each filter when used to its full extent is equivalent to a colour density of 1.

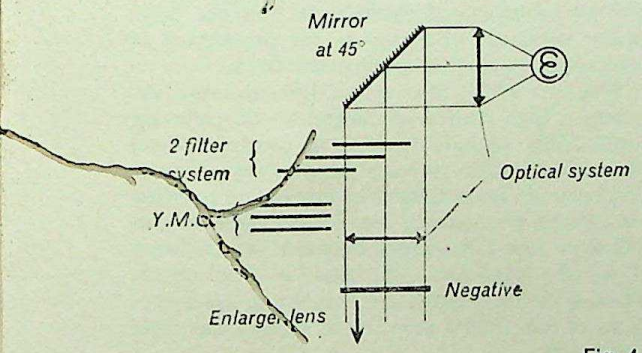
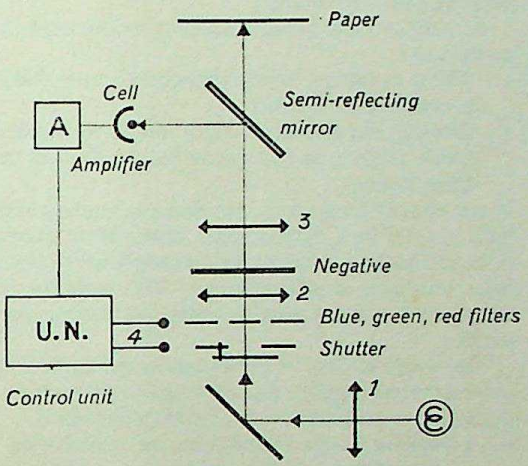


Fig. 4.

In practice only one or two filters are used for each exposure. By adjusting the amount of filter in the light beam any equivalent filtration between 0 and 1 in density can be obtained. The adjustment of the three filters is carried out by means of engraved knobs projecting from the enlarger head. A second set of filters is included which can be preset to correct for a particular batch of paper. To obtain the maximum accuracy in exposure an electronic timer is fitted in the lamp circuit. Where a fixed exposure time is used, the intensity of the light beam is altered, for example with the projection lens iris diaphragm. The correct aperture can be determined by measuring the light emerging from the lens with a photocell and galvanometer. The iris diaphragm is adjusted until the galvanometer reading reaches a predetermined value; in this way differences due to the negative density or to the insertion of subtractive filters are corrected.

B. Fully automatic printing equipment Equipment of this type is used for mass production of colour prints. The optical system is so arranged that light passing through the negative is measured by means of photocells which automatically correct exposures for deviations from standard readings through blue, green and red filters (Fig. 5).

Fig. 5.



1-2—Optical condenser
3—Enlarging lens
4—Automatic filter change and shutter mechanism

The measurements taken through the three filters are amplified and fed to a control unit which is the brain of the instrument and automatically adjusts the electrical and mechanical operations of printing to produce a standard result. In one type of instrument the negative is first graded by taking readings in red, green and blue light and the integrated densities thus obtained are used to set the timing of the printer so that a balanced print will be produced. This instrument has suitable delay circuits which store up the information from the grading system to be used during printing. In another system, grading and printing take place in three stages through additive filters; in the first stage exposure is made through a red filter and the amount of light passing through is used to operate a switch which cuts off the red beam when a predetermined amount of red light has passed. The process is then repeated using a green filter instead of the red, and again using a blue filter.

This second method is far simpler than the first but it has the disadvantage that the exposure adjustment is carried out by varying the time of

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

exposure thus introducing possible reciprocity effects. With the first system it is possible to use the equipment in such a way that the intensity of exposure rather than the time, is varied. Instruments of this type include the French Holweg printer, the Kodak IVC and S5 machines, as well as others marketed by film manufacturers and independent apparatus manufacturers. It should be pointed out that this type of printing equipment is only justified when vast quantities of prints are made and that the maintenance and setting up of these instruments can be undertaken only by skilled personel.

NEGATIVE-POSITIVE PROCESSES

In these processes the camera film is processed to give a colour negative; from this colour negative positive prints are made.

As with reversal films, the negative camera stock comprises:

1. Three emulsion layers sensitized respectively to red, green and blue.
2. During development three negative images (with respect to the exposure) are formed in these layers.

It can readily be seen (p. 36) that exposure to red light results in a cyan image; exposure to green light produces a magenta image; exposure to blue light produces a yellow image. The negative is therefore in colours complementary to those of the subject.

The positive film or paper has in principle the same construction (p. 36). After exposure through the negative and subsequent developing there is:

1. a positive image (relative to the negative exposure, that is, giving light areas in the final positive where there were light areas in the original subject).
2. the colours correspond with those of the original subject, using exactly the same principle that was described for the negative: original colour → complementary colour on the negative → positive in original colours.

In the section on the sensitometric characteristics of emulsions (see Sensitometry) it is shown that over a certain range there is a straight line relationship between the exposure given to a sensitive material and the resulting density.

Any part of the subject recorded on the toe or shoulder of the characteristic curve is shown in a different way, as in these regions, the photographic effect is far more difficult to express. We shall see later that the 'classical' work on photographic colour rendering called for the subject to be recorded on the straight line portion of the characteristic curve.

Negative gamma During the manufacture of a given product it is advisable to make the negative contrast as low as possible in order to extend to the utmost the latitude of the material: it must not be forgotten that the negative is solely a camera material and that all possibilities of improving its tolerance of errors are to be encouraged. The great success of black-and-white film in the hands of amateurs with cheap cameras having no exposure adjustment is primarily due to the exposure tolerance; acceptable results can be obtained with exposure which are several stops over or under the optimum.

In practice most negatives have a gamma between 0·4 and 0·8, the majority being around 0·6. The latitude of such films corresponds to an intensity range of 10,000 (a logarithmic range of 4) without appreciable distortion.

Positive gamma As the negative stage is designed to have such wide latitude, the positive must be quite contrasty and therefore possesses virtually no exposure latitude. A high gamma of 2 to 2·5 enables good blacks to be obtained quite easily; these are necessary in the production of images having good visual characteristics.

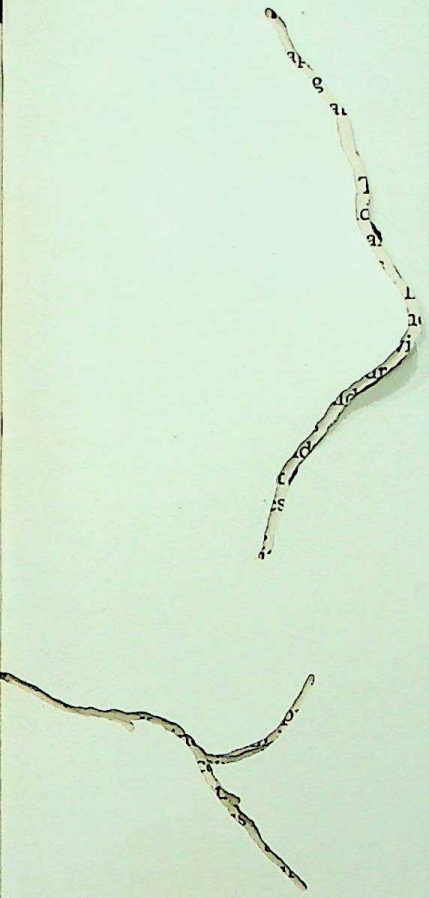
The lack of latitude in positive materials requires a high degree of control at the printing stage. This latitude requires a precise control of the relationship between the printing exposure and the negative density. For this reason printing equipment, particularly that for professional use, has very fine adjustment between the different steps, for example, $\sqrt[6]{2}$, that is ·05 log.E, whereas camera equipment is rarely graduated in steps of less than a stop, or in exceptional cases half a stop.

To obtain acceptable results, accurate control of contrast does not appear to be essential and it is always the case that the product of the negative and positive gammas is greater than 1.

The principal reason for this is that the sensitometric curve corresponding to a photographic image obtained using a camera, a printer and so on, does not correspond exactly with the curve obtained under sensitometric laboratory conditions used for emulsion investigations. The mechanical and optical conditions prevailing in camera and printing equipment differ appreciably from those in the sensitometer; for example the contrast in the shadows of a photograph made with normal equipment is always lower than the actual shadow contrast because of the presence of scattered light. Similarly, cinemas are not completely darkened and the diffused light tends to reduce contrast.

To these points, several other factors introduced

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Detail of carvings from
the cloisters of
Ottobeuren church,
Photo : H.W. Gelbing with
a Retina Reflex S,
fitted with 85 mm. telephoto,
Kodachrome daylight film,
exposure $\frac{1}{8}$ sec. *f*/8.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

by colour photography must be added. To increase the colour saturation it is usual to increase contrast and whilst this benefits the colour reproduction it is detrimental to tone reproduction. In the section on commercial materials, the practical negative and positive gammas are given together with the gamma product which is in the 1·8 to 1·9 region.

NIGHT PHOTOGRAPHY

Night photography is full of interesting possibilities when using colour film. Fascinating effects in the evening or at night are obtainable in the streets and squares.

Practical details The photography of illuminated buildings and monuments can be most rewarding in colour particularly when presented as a spectacle such as *Son et Lumière* where varied and often coloured lighting effects are used on the same monument. These subjects present no particular difficulty. Obviously a sturdy tripod must be used as exposures may be quite long and the lens hood should always be used. It is also advisable for this type of work to use a wide aperture lens and to use it at its maximum aperture consistent with good definition in order to keep exposures to the minimum. For this reason a lens having an aperture between *f*/2 and *f*/2·8 usually has its optimum definition between *f*/4 and *f*/5·6. There is no point in stopping down as this results in diffraction phenomena which equal or even exceed the slight improvement in definition. For most colour photography at night a tungsten balance film is used. This type of emulsion is usually preferable as most night effects are obtained with incandescent lamps. Streets lit with fluorescent lamps are an exception to this general rule. If these lamps give a very white light it is better to use daylight type film. This also applies to parks lit by mercury vapour lamps, sodium lamps, or coloured bulbs. Good night effects are often obtained before it is completely dark; there is still some light in the sky against which dark silhouettes of roof tops can be seen. Under these conditions the sky will be reproduced in the photograph as a very dark blue; this effect is preferred to the overall black effect which may even appear slightly greenish. The estimation of exposure is obviously of prime importance and is the only difficulty in this type of work. The use of very high sensitivity exposure meters is possible but in general is not very convenient. The table below will serve as a general guide for certain basic subjects.

If only the light sources themselves are to be shown against a dark background — advertising signs for example — quite brief exposures are possible, 1/20 to 1/5 sec. at *f*/3·5 to *f*/5·6 with 10 ASA film or 1/100 to 1/10 sec. at *f*/4·5 to *f*/8 with 100 ASA film. However, if some detail is required in the background, these exposures must be increased two-, three-, or even fourfold. When the subject is a firework display, the shutter is opened with the aperture at *f*/4 to *f*/11 (depending on the film speed) and the camera is left undisturbed to record on the same photograph an effective number of rockets, fountains, etc. A great difference in exposure will be required between very luminous objects, such as light-coloured floodlit masonry, and those which absorb light far more strongly, such as open spaces and gardens, although both types of subject receive the same illumination.

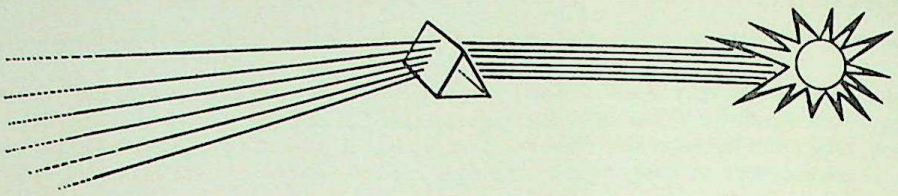
EXPOSURE GUIDE FOR NIGHT PHOTOGRAPHY WITH A COLOUR FILM OF 80-120 ASA

Street lamps, neon signs and Christmas illuminations only	1/30 sec.	*f*/4
The above but including some detail of streets and buildings	1/30 sec.	*f*/2.8
Well-lit shop windows	1/30 sec.	*f*/2
Average shop window	1/8–1/15	*f*/2
Floodlit buildings	30 sec.	*f*/5.6

J

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

P



PERUTZCOLOR FILM (Reversal colour film)

Perutz C14 and C18 films yield positive colour transparencies after exposure and reversal processing. Both types are balanced for normal daylight and can be exposed with blue-coated flashbulbs and electronic flash without a filter.

Perutz C14 (8 mm. double-width cine film only), daylight type, 20 ASA

Perutz C18 (35 mm. and roll film), daylight type, 50 ASA

Processing The film must be returned to the approved agent for processing in the bag supplied and the cost is included in the price of the film.

PHOTOGRAPHIC PROCESS (Basic)

When a photograph is taken the following procedure is followed:

1. Exposure of the sensitized negative material.
2. Development of a negative image.
3. Fixing.
4. Washing and drying.
5. Exposure of a second sensitized material through the negative.
6. Development of this latter material to form a positive, which also has to be fixed, washed and dried.

A. The photosensitive system (emulsions) A normal photographic layer consists of a large number of silver halide crystals (grains) dispersed in a gelatin layer.

This mixture of grains + gelatin is usually called a photographic emulsion, or more simply emulsion. From the physio-chemical point of view this is an incorrect term. The correct term is 'suspension', as emulsion is used to designate the dispersion of liquid particles in another liquid. The term emulsion has, however, become accepted over the years.

In practice silver bromide is the most widely used of the silver halides and generally a small proportion of silver iodide is mixed with it. Some slow emulsions, particularly for papers, use chloride or chlorobromide emulsion.

The emulsion must obviously be applied to a suitable base before it can be used to take a photograph. With films a cellulose ester is generally used but paper and glass are other common supports; for special purposes almost any solid transparent or reflecting material can be used.

B. Latent image To be effective in initiating a photomechanical reaction light must be absorbed according to the Grothus, Draper Law.

Normally the effect of slight irradiation of an emulsion layer is not visible to the eye. However, a change has taken place and the latent image produced can be made visible by the simple process of development.

C. Development A developing solution is one which reacts preferentially on exposed rather than unexposed silver halide grains, reducing them to metallic silver in a relatively short time. In other words a developer is simply a reducing agent which acts on the exposed grains first. The selected reducing agent is used in solution with other compounds which modify and control the development reaction. The complete solution is simply called 'developer'.

When a developed image is examined through a microscope it will be noted that it consists of small metallic silver particles. To some extent the developed silver grains correspond with the silver halide grains of the original emulsion but there is a tendency for several grains to coalesce.

D. Fog If development of a photographic layer is continued long enough all the silver bromide, exposed or not, will be reduced to metallic silver. Even during a normal development period some unexposed grains will be developed producing a thin overall deposit of silver over the film or paper. This unwanted deposit is called photographic fog.

E. Fixing Residual undeveloped silver halide is removed from the emulsion layer by fixing. This is achieved by treatment in a solution which generally consists of a thiosulphate — sodium or

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

ammonium being the usual salts. The removal of residual silver halide is necessary to prevent further darkening on exposure to light.

F. The negative and the positive The exposure and development of a sensitized photographic layer gives a negative in which the highlights and the shadows of the subject are inverted. To obtain a positive a second sensitized layer (generally with different photographic properties) is exposed through the negative; it is developed, fixed and washed as before.

PHOTOGRAPHIC REPRODUCTION OF COLOUR

1. General The principles explained in the section on colorimetry show the general theory and mechanics of photographic colour reproduction.

The eye's ability to synthesize by mixing results in the production of a wide visual range of natural colours. This three-colour system is the explanation of the basis of all modern colour processes which may use either a three-colour réseau as in the additive processes, or three superimposed colour emulsion layers common to the subtractive processes. In these theoretical processes two phases can be separated — the analysis and the synthesis.

This distinction will be maintained throughout the following explanations. All processes, whether additive or subtractive, involve a similar analysis through blue, green and red filters; from this analysis the proportion of blue, green and red required to give a correct reproduction is obtained, varying according to the process.

As explained in the section 'Colour Image Quality' (page 43) this spectral sensitivity of colour emulsions for this work should correspond to the colour mixture curves of the trichromatic synthesis.

2. Three-colour analysis Panchromatic emulsions are normally used for three-colour analysis together with filters to obtain the required spectral cut-off or by the use of specially sensitized emulsions (see Spectral Sensitivity).

In practice the analysis is carried out successively for stationary objects or simultaneously. In the latter case it can be carried out on three independent emulsions or on a single film containing three emulsions such as an integral tripack.

Successive analysis This is the simplest system as an ordinary panchromatic emulsion can be used. The stationary subject is placed in front of an ordinary camera and three photographs are taken: one behind a blue filter, the second behind a green filter and the third behind a red filter. The combination of the filter curves together with the emulsion sensitivity should correspond to the mixture curves of the reproduction system. The object of this analysis is to obtain a balanced set of three photographic negatives (see Sensitometric Quality of Emulsions and Exposure Latitude). The best colour reproduction is almost invariably obtained when greys are reproduced as true neutrals. Experience has shown that any colour process which cannot produce good greys has not the qualities needed for commercial purposes.

A three-colour set of separation negatives are said to be balanced when their density and contrast are substantially equal. The advantage of the system in which three separate negatives are made is that the negatives can be exposed and processed for different times so that a correct balance of density and contrast can be obtained between them. The main disadvantage is of course that the subject must be absolutely still otherwise colour fringes will be present spoiling the quality of the final print. Whilst the preparation of separation negatives is rarely used in normal colour photographic work, even for colour photographs of documents and other static objects, it is widely used in the graphic arts field as an essential step in the preparation of all types of multi-colour printing plates.

Simultaneous analysis Various methods of simultaneously exposing the three plates necessary for three-colour analysis have been suggested. The classic method which undoubtedly gives the best possible results is to expose three plates in a 'one-shot' camera which contains one lens, two semi-reflecting mirrors and three plate holders, each of which is fitted with one of a set of three-colour filters. The semi-reflecting mirrors split the light beam into three parts, reflecting and transmitting similar images on to the three plates. The disadvantages of these cameras are bulk, expense and luminous inefficiency.

Lumière's Autochrome can be considered as a system of simultaneous analysis, as can Dufaycolor and other screen processes (see Additive Processes). The réseau processes have now been virtually abandoned despite their one-time popularity in favour of the integral tripack materials. Recently there has been a revival of interest in the additive lenticulated film processes (original Kodacolor, Agfacolor) for the recording of colour television programmes.

Integral tripacks In this type of process three emulsions are superimposed and sensitized in such a way that with or without filters they are effectively sensitive only to blue, green or red

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

light respectively. The practice of superimposing emulsions inevitably results in a loss of sharpness due to the spatial displacement of the three images as well as to the light scattering caused by the turbidity of the emulsion through which the light affecting two layers has to pass. A partial answer to this problem is to use a bipack for recording two of the images, a third image being recorded on a separate plate using a simple light-dividing system. This compromise system was used very widely at one time in the Technicolor beam splitter camera but the integral tripack demanding no special camera equipment has now been improved far enough for the beam splitter systems to be abandoned.

The first practical integral tripacks were the Kodachrome process in the USA and the Agfacolor in Germany; both were reversal processes at the time of their introduction in 1935. To achieve satisfactory results with materials of this type it is essential that they should be well balanced — one emulsion must not be greatly over-exposed relative to the other two. The layer order depends on the type of emulsion and upon the use to which the material is put. Camera stocks generally have to have high sensitivity to enable them to be used under all types of lighting conditions, particularly when exposures are fixed, as in motion picture work. This means that iodobromide emulsions must be used whose intrinsic sensitivity forces the manufacturer to place the blue sensitive layer at the top of the pack. This is followed by a yellow filter layer, then by the green and red sensitive layers. Any other position for the blue sensitive layer would not be possible owing to the intrinsic sensitivity of the green and red sensitive layers which must be effectively cut out by means of the yellow filter layer. With papers and print film, on the other hand, sensitivity is not as important and other emulsions can be used. It is becoming a common practice to make these slower colour materials using chlorobromide emulsions whose intrinsic sensitivity is in the ultraviolet and far blue; by using suitable dyestuff sensitizers the emulsions can be sensitized to any single desired spectral region and therefore any coating order can be used; for example a green sensitive top layer followed by a red sensitive middle layer with the blue sensitive layer next to the base. By using such a layer order improved sharpness of the print can be obtained.

3. Three-colour synthesis methods The numerous methods of colour synthesis can be divided into two groups:

additive synthesis
subtractive synthesis

(a) Methods of additive synthesis These descend directly from basic colorimetric principles. As we have seen, the three basic colours blue, green and red, mixed in various proportions, reconstitute in the eye the colour of the photographed object. The separation images corresponding to the blue, green and red can be either macroscopically separated on their own bases or side by side on a single base, or may be microscopically positioned on a single base, as we shall see later.

Images geometrically separated or side by side on a single base The practical methods using this procedure must provide for an optical system which will recombine the three images during projection. One of the classical examples in the commercial cinema was Gaumont Color, in which the 35 mm. film contained side-by-side images. During projection the film passed behind a three-lens system which combined the images on to the same screen. Due to the camera optical system there were parallax difficulties showing colour fringes on the screen. In the Francita process three substandard images were formed on a 35 mm. film and while this gave improved results, parallax was still present. The Rouxcolor system used a beam-splitting device which was free from parallax at the focusing plane, but fringes were still present in front of and beyond this plane. No commercial system based on this additive method is at present in use. The complex optics of the projector synthesis element associated with these additive systems may cause considerable losses of screen brilliance due to the number of glass/air reflecting surfaces involved, each of which can contribute to an appreciable reduction of contrast.

Additive systems having adjacent colour elements This includes Autochrome, Dufaycolor, Finlaycolour, as well as the lenticular processes based on the Berthon process.

In this case the optical problem is greatly simplified but is replaced by a further problem: the poor resolution of these adjacent colour elements. In the Lumière Autochrome process (the oldest process of the group), a combined analysis and synthesis réseau was made up of dyed starch grains — red, green and blue — dispersed at random in a layer one grain thick. In both the Dufay and Finlay processes the réseau was printed photomechanically and particularly in the case of Dufay gave a very fine réseau. The final quality of the image was to a large extent dependent on the fineness and other qualities of the réseau.

One important feature of all these réseau processes is that the filter elements serve the double purpose of analysis and synthesis filters.

(b) Subtractive synthesis In the section on the theory of colour mixing, it was shown that the

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

dyes whose spectral characteristics correspond to the absorption of one-third of the spectrum and transmit the remaining two-thirds (yellow, magenta and cyan dyestuffs) give a reduction of the three primary spectrum colours, blue, green and red, when they are mixed in appropriate proportions that correspond to the photographic effect of a side-by-side element additive process. In fact, in the case of the cyan dyestuff it can be seen that its purpose is to modulate the red light or the red constituent part of white light. The two other constituent parts, blue and green, should not be affected. The green light on the other hand will be modulated by the magenta image, which will not affect the red light, and the blue light will not have been affected by either the magenta or cyan images. Finally a yellow image on top of the cyan and magenta images will serve to modulate the blue light and therefore enable all the primaries to be modulated according to the amounts of cyan, magenta or yellow image present. The three coloured images are made to correspond to the densities of the analysis negatives taken through the red, green and blue filters.

It can readily be seen that the subtractive system has many practical advantages, and to name only one — the saving of light during projection. Whereas with additive projection two-thirds of the light is wasted due to the absorption by filters, subtractive projection uses all the light transmitted by the optical system and film, with no more loss of light than occurs with normal monochrome projection.

Furthermore the use of tripacks gives the photographer and the technician a completely parallel material so that their work with colour conforms very closely to that with black-and-white. The way in which an integral tripack sensitized to blue, green and red light is exposed and processed to three layers, yellow, magenta and cyan (see diagram in section on Colorimetry) is of great importance.

Before going deeply into the various processes it should be noted that none of the ideal dyestuffs are yet attainable but all processes use dyes which are sufficiently close to be of practical value. Finally it should be noted that in the section on masking it was shown that although many dyestuffs do not have the spectral characteristics which are required, automatic or non-automatic masking techniques can be used which will bring their characteristics very close to the theoretical requirements.

The methods used to produce a colour image from a photographic image fall into three main classes.

1. The colour development processes which, with one exception, are the basis of all modern colour photography and cinematography.
2. The imbibition processes which, with the exception of the Technicolor process, are tending to lose ground commercially.
3. The various relief processes which are used to produce a variation in the quantity or density of dyestuff or pigment. In general all the methods are based upon the presence at some stage of a silver image. The dye image may be produced at the same time as the silver image or later.

During the development of silver halides various by-products are formed — developing agent oxidation products, alkali halides and halogen acids. Only the metallic silver and the developer oxidation products can have at present any use. The way in which the silver and the developing agent products can be used is shown in the chart on page 126.

In some processes the silver halides are not used but are replaced by other photosensitive systems — bichromates, diazonium compounds, ferricyanides, etc. These may not be very important in colour photography but some are extremely important in the photomechanical trades (bichromates) or the reproduction of plans (potassium ferricyanide plus ferricammonium oxalate used as blue-print sensitizer).

In all cases where a silver image is used as an intermediate to the colour image it must be eliminated. All the major colour photography processes incorporate bleach baths or systems. As the silver image makes no direct contribution in the majority of cases one could reasonably expect the non-silver processes to be more successful but the main reason for the unrivalled success of the silver halide processes is that they are something like 100 million times more sensitive than other processes.

COLOUR DEVELOPMENT

Colour development was suggested as a practical procedure by Fischer in 1914 and permits coloured images to be obtained very easily in a photographic layer.

To explain colour development the chemistry of development must be briefly recalled. In the presence of certain mild reducing agents called developing agents, silver halide crystals which have been exposed to light, are rapidly reduced to silver whereas those which have not been exposed to light are not reduced at a comparable rate. At the same time as the silver halide crystals are reduced to metallic silver it is necessary that a corresponding quantity of developing agent should be oxidized to preserve chemical equilibrium. Normally the developing solution contains substances which react with the oxidized developing agent to prevent it from having adverse effects on the silver image or on image formation. This elimination of developing agent products so necessary in black-and-white photography does not apply in colour work. It was

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

COLOUR PHOTOGRAPHY REPRODUCTION PROCESSES.

METHODS	COMMERCIAL APPLICATIONS
A. COLOUR DEVELOPMENT	
1. Couplers in the developer.	Kodachrome, Ilfachrome, Kodachrome-print (Minicolor).
2. Couplers in the emulsions.	
(*a*) Directly dispersed in the gelatin.	Agfacolor, Gevacolor, Ferraniacolor, Anscocolor, Telcolor.
(*b*) Insoluble salts.	
(*c*) Soluble in an oily substance dispersed in the emulsion.	Kodacolor, Ektachrome, Ektacolor.
(*d*) Chemically combined with the colloid binder.	Dupont positive cine film.
B. DIFFERENTIAL TANNING OF THE GELATIN	
1. Obtaining relief from pigmented gelatin layers.	
(*a*) Direct exposure to light of bichromate gelatin.	Carbon process
(*b*) Gelatin containing bichromate and ferricyanide placed in contact with the silver image.	Carbro.
(*c*) Tanned development.	Duxochrome.
(*d*) Tanning bleach with bichromate of a silver image.	
(*e*) Degrading bleach of a silver image by hydrogen peroxide.	
2. Obtaining reliefs, starting from gelatin layers dyed subsequently.	
(*a*) Direct exposure to light of bichromate gelatin.	
(*b*) Tanning development:	
(*i*) Gelatin relief absorbing dyestuff after mordanting.	
(*ii*) Gelatin relief soaked by dyestuff transferred to mordanted gelatin.	Kodak Dye Transfer, Technicolor.
(*c*) Tanning bleach.	
(*i*) Gelatin relief soaked in dyestuff, transferred to mordanted gelatin.	Wash off relief.
3. Obtaining flat surfaces showing variations in local tanning.	
(*a*) Untanned parts absorb the dyestuff.	Pinatype.
(*b*) Untanned parts absorb water, tanned parts a mixture of oil and dyestuff.	Collotype Bromoil.
C. CHEMICAL TONING	
1. Silver image turned into coloured pigment.	Chromotone.
2. Silver image turned into mordant.	Traube (iodide process).
3. Process 1 and 2 mixed.	Supercinecolor.
4. Combination of process 2 with Pinatype.	Chimicolor, Thomsoncolor.
D. BLEACHING OF DYE IN CONTACT WITH A SILVER IMAGE	
1. Catalytic.	Christensen process.
2. Oxide reduction.	Gaspar Color and Bauchet process.
E. PROCESSES NOT USING SILVER HALIDE	
1. Direct destruction of the dyestuff.	Utocolor.
2. Pigmented gelatin layers, sensitized by bichromate-gelatin.	Carbon process, Carbro and photo-mechanical process.
3. Diazonium process.	Ozalid process.
4. Gelatin layers containing potassium ferricyanide and ferric ammonium oxalate.	Blue-print process for plans.

Homulka who first noted the stain produced by the oxidation products of developers and that this stain was sufficiently strongly attached to the gelatin in certain cases to be capable of practical image formation. The range of colours available to Homulka was, however, extremely limited and it was not until Fischer modified Homulka's 'primary colour development' technique where the image is produced by the developer's oxidation product to 'secondary colour development' where the developer's oxidation product couples with another compound present in the solution or in the emulsion that more brilliant dyes were obtained. The product which combines with the

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

developer oxidation product is called a colour coupler. The photographic occurrence which particularly attracted Fischer's attention was very close to a well-known reaction in organic chemistry. Aminoaniline and its derivatives will combine with phenols and naphthols under suitable oxidizing conditions to give a class of dyestuffs known as the indophenols.

The exposed silver halide of a photographic emulsion provides the necessary oxidizing conditions. In the presence of suitable adjuvants para-aminoaniline has enough reducing activity to develop a photographic image and become oxidized. It is this oxidation product that will combine with a coupler to give dyestuffs. This ability to form an image at normal temperature and in a convenient time has been a major factor in the present success of colour development processes. The couplers which give cyan images when using aminoaniline developing agents are derivatives of phenols and naphthols exclusively. The couplers giving yellow and magenta dyes have other characteristic groups which will be described later.

The colour of the dye can be altered by changing the constitution of the coupler; this was one of Fischer's main contributions as he realized the extent of the variety of dyestuffs which could be produced by his system compared with the restricted range produced by Homulka's primary colour development.

It should be noted that apart from the straightforwardness of the colour development process there is little to recommend the classes of dyes which it produces; neither the indophenol nor the azamethine dyes have any industrial application apart from colour photography as they are too unstable. One of the basic problems of colour photography and cinematography, and this applies particularly to enlargements which may be used for decoration, is the question of print stabilization. It is a constant task of manufacturers to improve materials from this point of view.

The various systems will not be described according to the technique used for introducing the couplers.

Couplers in developers This system was originally used with the Eastman Kodak Kodachrome process and is now used by many other manufacturers. Among the advantages of this system are the relative cost of manufacture of a coupler free material and the greater stability of the product. Against this is the greater difficulty of processing with the necessity for a very much closer degree of control at seven critical processing stages instead of the usual two.

Systems with incorporated couplers It must first be assumed that any interaction between the couplers and the emulsion has been eliminated. In designing couplers to be incorporated in emulsions their tendency to wander from one layer to another must be eliminated by combining the coupler molecule with another molecule which will prevent any diffusion from the layer in which the coupler is incorporated. The modification of the coupler molecule to prevent its diffusion must be accompanied by a further modification to preserve its water solubility so that coating is not made excessively difficult. Incorporated couplers may have effects on sharpness and graininess of the final image characteristics. Any foreign matter introduced into an emulsion layer will tend in fact to increase its thickness and from what was shown in the section on Quality of Colour Prints it will have been noted that any tendency to increase the thickness of an emulsion layer will adversely affect the sharpness of a colour image. The thicker the layer the less sharp the image and therefore, other things being equal, any material with incorporated couplers will tend to be less sharp than materials using dissolved couplers. Furthermore the incorporated coupler system tends to produce graininess that is higher than any system which does not use incorporated couplers. Finally the presence of residual couplers together with dyestuffs is an unfavourable factor in the light stability of the resulting colour photographs. The fundamental advantage of the incorporated coupler system is that colour development is carried out in one bath only and processing is infinitely simpler than is a process like Kodachrome. The commercial availability of materials containing couplers enabled commercial finishers and amateurs to carry out their own processing. This is an advantage despite the greater complexities of manufacture of the raw stock.

Imbibition processes The basis of this process is that of the image-wise hardening effect produced by some developers. As in colour development it is the oxidation product which does the useful work and in this case the selected developing agent (pyrogallol for example) produces an oxidation product which locally hardens the gelatin where the silver halide is reduced. Its action is to produce cross linkages between the long chain members of the gelatin molecules and so produce a less soluble colloid. By subsequently washing in warm water the hardened and developed parts remain attached to the base and the undeveloped sections are washed away leaving a relief image. The same result can be obtained by normal development followed by bleaching in a tanning bleach, for example a bichromate bleach. The chromic ion produced during this reaction locally tans the gelatin (wash-off relief). To retain the relief on the base, exposure should always be made through the base. To obtain a sharper relief the emulsion layer should contain a dye which absorbs the

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

light used to expose a layer. The dye also restricts the depth to which the light penetrates and produces a better and more compact relief.

This gelatin relief or 'matrix' can take up dye from a solution of the dye and transfer this dye solution to a suitably prepared layer in proportion to the amount of dye taken up — that is to the thickness of the matrix or to the amount of exposure which the sensitive layer originally received. The transfer operation can be carried out a large number of times. Obviously this process cannot be applied to a multi-layer system but only to individual elementary images. These should contain suitable register marks so that a set of images (three for example) can be superimposed in register on a suitable base to give a final colour copy. The registration system may vary from the simple blanket method used when one print is made by the dye transfer system to the complexities of the enormous stainless steel pin belt used to register motion picture film being transferred at over 200 ft. per minute by the Technicolor system.

Processes dependent upon differential hardening of gelatin The imbibition system is dealt with first because of its considerable commercial application in the Technicolor process. Under this heading all processes of a similar nature depending upon differential hardening of gelatin are considered together (see chart). The way in which the various processes differ between themselves is in the nature of the light-sensitive material — bichromate or silver halide and whether or not the light-sensitive layer itself contains the dye or pigment used to form the positive colour image.

(*a*) Gelatin layer containing silver halide: the relief can be obtained by tanning development as with the imbibition processes.

(*b*) Duxochrome (q.v.) uses pigmented layers sensitized with silver halides.

(*c*) Bichromate sensitized gelatin layers: these elements are very much less sensitive than the silver halide layers just described and are exposed to very intense ultra-violet light from a mercury or arc lamp; this breaks down the bichromate ion and the locally produced chromic ion hardens the gelatin where exposure has taken place.

The introduction of coloured pigments in yellow, magenta and cyan gelatin layers give the following processes:

(*a*) Carbro (q.v.) is derived from this process but instead of using light to bring about the local hardening of the bichromated gelatin, a positive silver image is used.

(*b*) Carbon (q.v.): pigmented layer sensitized by bichromate.

Processes by toning, mordanting, dye bleaching and dye destruction As none of these processes have had any great commercial application they will not be considered at length here. Readers are referred to the following headings for descriptions of the processes which have had some commercial development: Chromatone, Supercinecolor, Chimicolor, Gasparcolor, Utocolor.

PHOTOMECHANICAL PRINTING

Colour photographs which are to be used in books, journals and in other printed publications, are reproduced by means of one of the following printing processes: letterpress, offset, or photogravure.

The choice of process is determined by considerations of size, quality required, number of copies, and cost.

Whichever process is used, the reproduction is based upon the same principles as subtractive colour photography. Instead of the three layers bearing yellow, magenta and cyan images, there are three printing plates which successively print images of these colours. A fourth plate — usually black — if often used to improve definition and register.

LETTERPRESS

This process is the oldest and still the most widely used. The printing areas are raised and the corresponding recesses receive no ink and do not come in contact with the paper surface — they give the white areas of the image.

Taken individually each colour plate has the same structure as a plate used for monochrome letterpress printing. This is the screen plate in which the different densities are made up of extremely fine dots, the dots being large or small according to the density. The optical mixing of these dots with the white of the paper gives an impression of grey.

By examining a monochrome half-tone reproduction with a lens it can be seen that the image is made up of a mixture of large and small dots and consequently small or large white areas. Medium grey areas have a chessboard pattern of black areas given by the high parts of the plate and white areas given by the reliefs. As the grey becomes lighter the white squares spread until their corners join and the black squares shrink in area and gradually take the form of round dots.

The proportion of black and white gives the sensation of a more or less light grey which becomes almost white when the area of the dots

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

shrinks to the low limit; conversely when passing from a medium grey to black it is the black squares which gradually spread over the white squares which shrink into smaller and smaller and more widely separated dots. The total disappearance of these dots gives black.

When the black ink is replaced by a coloured one the gradation of this colour follows the same pattern.

The screen The conversion of a continuous tone photograph into a pattern of large and small dots is brought about by photographic printing through a screen. Half-tone screens are made up of two glass plates engraved with lines which are filled with an opaque substance; they are assembled so that the lines cross at right angles. The clear parts obtained in this way generally have the same area as the opaque parts.

The distance between the opaque lines which determines the fineness of the screen varies. It is chosen according to the paper which will be used for printing; this may be an irregular surface such as newsprint or a very smooth surface used for the highest quality printing. The finer the screen the higher the quality of paper which must be used.

The screens are classified according to the number of lines per inch. Those used in colour printing are 133, 150, 175, and 200.

Formation of the screen image Having focused and composed the original on the ground-glass screen of a process camera, the half-tone screen is positioned in front of and parallel to the ground-glass. Each transparent area projects a cone of light surrounded by a partial shadow area which translates the variation of brightness into a variation of area. The base of the cones is not geometrically regular but is affected by the shape of the diaphragm which is usually square not circular. Medium grey is formed by a group of elements of the shape of the diaphragm, giving a chessboard effect when the diaphragm is square. A dark grey is formed of smaller and consequently separated bright areas whilst in the lighter greys the bright areas spread and join up. The larger shadow areas correspond to the darker image areas.

For correct formation of the screen image on the sensitive surface and for correct translation of the density variations, the ratio between the screen and the ground-glass (or the sensitive surface) must be correctly adjusted; it can vary between 64 and 90 times the grid spacing depending upon the process camera and the diaphragm opening.

The negative obtained behind the screen does not consist of completely opaque and transparent areas. The image does not consist of spots with definite edges but of light dots surrounded by large or small shadow regions. The image still has density variations despite its screen pattern.

To reduce the grey areas to a minimum the negative is made on a high contrast emulsion of the type used for line reproduction. The edge sharpness of each point and the required density are achieved by an intensifier which acts mainly on the dark parts followed by a reducer which cleans the highlights.

Etching The printing plate is a positive image on zinc or copper, the raised parts forming the dark areas and the relief areas the highlights. If this positive shows the subject the right way round the print on to paper will be reversed and it is therefore necessary to reverse the negative.

To obtain the positive image the metal plate must be sensitized — covered with a light-sensitive layer which is generally coated from a solution of fish glue and ammonium dichromate.

The negative is brought into intimate contact with the sensitized metal plate which is exposed by means of an arc lamp. The plate is then 'developed' with a jet of water. The areas which have not been exposed to the light remain soluble and leave bare metal in all the areas which are to be white in the final image. The relief image is then formed by etching with dilute nitric acid in the case of zinc plates or with ferric chloride solution for copper.

The depth of etching must vary according to the image density. The maximum depth being required in the extreme highlights and in the margins. A single etching stage does not give the required results and it is necessary to etch in successive stages to control the depth of the relief and the contrast of the final image. The block-maker must treat the various areas individually, being guided by the original and his own experience.

To obtain the best contrast the etching of the shadows is stopped first and these are protected from further action with a coating of varnish.

In the second etching stage the mid-tones are primarily treated although the highlights are etched at the same time. The mid-tones are then protected with varnish while the highlight areas are finally etched to the required degree. This process of 'fine etching' is carried out with continuous reference to the original and requires considerable skill. Engraving is completed by mechanical cleaning out and deepening of the relief, particularly in the areas which are to be reproduced completely white and which must therefore pick up no ink.

In the reproduction of colour images the different etching stages (fine etching) is extremely important as it enables the three colour images to be correctly balanced and colour distortion to be largely corrected.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

OFFSET

A good half-tone print requires the use of a coated paper for black-and-white and consequently for colour reproduction. To avoid the use of a coated paper, a printing plate is required which is less sensitive to surface irregularities. Reliefs are avoided and the screen is treated lithographically on a slightly grained zinc foil.

In lithographic printing the printing paper is everywhere in contact with the stone carrying the greasy pencil or greasy ink image. After treating with a very dilute aqueous solution of gum arabic and sulphuric acid, a stone is placed in the press and wetted. The ink which is applied with a roller is only accepted by the parts carrying the design. It is repelled by the unprotected areas of the stone which have taken up water. In the press the ink which was accepted by the design is transferred on to the paper.

When printing from zinc foil the screen image does not give very satisfactory results and greater flexibility is obtained if the ink is first transferred to an intermediate rubber-covered roller. An offset press must therefore have three cylinders; first the zinc foil with the image on it the right way round, then the rubber-covered roller in contact with the zinc which receives the ink image in reverse, and finally the roller carrying the paper. This takes the ink from the intermediate roller, the image again becoming the right way round.

Photographic operations The preliminary photographic operations are the same as for half-tone. The same screen photography and treatment of the negative. From this negative a positive is printed on to film; this is necessary because the zinc sheet unlike the half-tone relief has the highlights protected whilst the printing areas are slightly etched. The fine etching of half-tone is replaced by local intensification and reduction of the film positive. This is to reduce the size of the dot in the highlights as in half-tone, and to ensure sufficient density in the shadows to reproduce the contrast of the original.

Printing on to the metal The zinc foil is sensitized with a solution of gum arabic and ammonium bichromate and then exposed in contact with the film positive using an arc lamp. The areas of the plate corresponding to the transparent areas of the positive are hardened by the light. Water development exposes the metal under the opaque dots of the screen image. Very slight etching is followed by greasing, inking, and elimination of the hardened layer in the highlights. Finally the zinc foil is prepared as for a lithograph and placed in the press.

PHOTOGRAVURE

Photogravure is a process in which the ink is carried in the hollows etched in the plate. If a gravure print, or better still the copper plate from which it is made, is examined with a magnifier, it is seen that the variations in density are produced by variations in the thickness of the ink present in the lines or hollows of varying depths. Lines which are close together but which are shallow give grey, whilst lines of the same width but which are deeper result in a darker area. It can be seen that the thickness of the ink deposit is the important factor and that this is independent of the effect produced by the design.

Photogravure, having this special form of printing from a hollow, does not use a screen and the pattern which is seen with a lens has no part in the production of varying gradation. The pattern is there only to form small recesses which hold the ink better and control the removal of the excess ink which is carried out by a wiping process. Contrary to half-tone processes, photogravure requires a positive photograph instead of a negative. The image formed in the copper representing the range of gradations, and the unaffected surface the pure whites.

Photographic operations In monochrome photogravure the original to be reproduced is generally a photographic print and the first operation is to produce a suitable negative. This negative is spotted and retouched if necessary, either to cover spots or handling faults or to adjust the contrast and accentuate the shadow detail. The negative should be exposed through the base and not on the emulsion face so that the positive image will be reversed left to right. In turn the positive is retouched and its contrast is adjusted to give the requisite detail in both shadows and highlights. If an original negative rather than a re-photographed one can be used, a positive with better gradation will be obtained.

Transfer on to copper In photogravure the metal is not sensitized directly; the image is transferred on to the copper via a negative print on carbon paper which is made from the positive. The carbon process will not be described here as the principle has already been discussed under 'Carbon Process'.

The pigmented paper is sensitized, exposed under the positive, or the group of positives which will finally go together on the printing cylinder, and is then hot water developed on the copper. This transfer is preceded by a first stage which is the transfer of a pattern to grain the image surface. The cylinder is now covered with a coloured gelatin layer in which the differences in thickness correspond inversely to the different densities of the image. These differences in thickness, by modifying the action of the acid, bring about the range of etching depth.

Ferric chloride in solutions of different strength

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

is used as the mordant. The more concentrated the solution, the less will it penetrate the gelatin and vice versa. To obtain an image with a wide density range the successive etching steps proceed with weaker and weaker solutions. The first, which is a strong solution (40°Be), only acts on the areas covered with a thin layer of gelatin, the deep blacks. The second stage (39°Be) affects only the dark half-tones; the third at 38°Be, the lightest densities, whilst the fourth at 37°Be penetrates the greater gelatin thicknesses and is responsible for the highlight detail.

Although carried out in a different way to half-tone etching, the etching of photogravure enables the same controls over contrast and colour balance to be exercised.

Printing The principle of the photogravure press is extremely simple. A large cylinder carrying the sheet of paper revolves in contact with the engraved cylinder. The lower part of the latter dips into a dish filled with a very fluid and volatile ink. As only the printing area must retain ink, the surface of the copper is mechanically squeegeed with a steel blade which is extremely sharp and in absolute contact with the cylinder throughout its length. As this blade is supported by the mesh of the grid it does not reach the bottom of the relief and leaves the ink intact in the hollows. As only one stroke of the blade is possible — that which wipes the ink from the extreme highlights — there is no control over the amount of ink deposited in the hollows. A print which is too dark can only be improved overall by adding to the ink a certain amount of solvent which produces a general lightening. Small areas, however, can be lightened by means of fine abrasive used lightly on the copper surface.

PHOTOGRAPHIC TECHNIQUE

As with any of the photographic build-up processes of colour printing, carbro, dye transfer, etc, each set of blocks requires a set of separations made through the three primary filters, red, green and blue from a colour original. These separations are generally made by the photo-engraver and can be direct or indirect.

Direct separation If the original to be reproduced is a photographic paper print, a picture, etc, each screen negative is obtained at the same time as the separation. The sensitive material is a high contrast film (Process Pan). The separations are made with the usual three filters.

Blue for the yellow plate
Green for the magenta plate
Red for the cyan plate

Bearing in mind that each filter will require a different exposure for each type of emulsion (recommendations are normally given with each box of material), two precautions are essential: the first is the use of a prism mounted on the lens giving laterally reversed negatives whose register must be exact. The second is a different orientation of the screen and the diaphragm for each colour in order to avoid a moiré pattern and to obtain a better distribution of the dots and avoid the effect which may give a subtractive synthesis where dots overlap or are superimposed, and an additive synthesis where the dots lie alongside each other. The orientation which is given for the three filters is:

45° for the red filter (cyan image)
75° for the blue filter (yellow image)
105° for the green filter (magenta image)

When a fourth colour—generally black—is used, the orientation of the screen is 90°, or alternatively this angle may be given to the cyan and 45° used for the fourth colour.

Indirect separation When the blockmaker's original is a colour negative or transparency, or is a set of soft gradation unscreened separations, indirect separation is necessary.

In the case of subtractive transparencies, separations are made on continuous tone emulsions. From the three separation negatives, contact screen positives are made on hard emulsions. These positives are then contact printed to give the final screen negatives.

The use of a subtractive colour negative enables screen separation positives to be made directly in a single operation. This procedure is particularly recommended for offset.

The succession of steps in the preparation of the

DIRECT SEPARATIONS

LETTERPRESS	OFFSET	GRAVURE
Screen separations	Screen separations Positives Printing plates or Colour negatives Screen separation positives Printing plates	Separation negatives Positives Carbon paper Printing cylinder

see diagram on page 38

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

plates is given in the tables; in the case of gravure (and also for other processes where high quality is required) the steps shown are not enough to give good reproduction. The introduction of the photographic process of 'masking' between the original separation and the final stage is necessary. These processes are described under this heading.

A solution has been found to most of the difficulties which face the blockmaker in obtaining good colour reproduction, and if today frequent minor faults are seen they are not necessarily due to lack of professional skill.

Before the photographer had the integral tripacks which allow photography under almost all conditions, the blockmaker was in an advantageous position. The majority of his work was with documents, paintings, fabrics, and so on with relatively short scale; these could be photographed by direct separation giving low colour distortion and a degree of control which enables almost perfect contrast matching to be achieved.

Now he is faced with the same difficulties as the photographer who wishes to make paper prints — the subject brightness range usually exceeds that of the process, and even when an acceptable print is obtained it can rarely bear comparison with the original.

There is one major difficulty which seems insuperable — the range from maximum to minimum density in the print. In the best conditions the range is limited to 30:1 (corresponding to a density of 1·5); if the original is a transparency it may, with its maximum density of 2·5 to 3·0, have a range of 250:1.

Furthermore, the difficulties in obtaining suitable photographically produced image dyes are exceeded by those of producing good printing inks. Dark colours are only obtained at the expense of saturated ones and this increases the practical importance of a fourth printer.

It can be said that texture apart, a picture can be correctly reproduced, irrespective of colour, if its range does not exceed that of the print process. Taking into account the size of the print, which can affect the colour rendering, each tint on the print can be compared with that of the original to give satisfactory rendering. This does not apply to every subject in nature or in the studio with particular lighting — such comparisons are not possible. It is the colour photograph which is the blockmakers' original and which must be reproduced even though it is only an intermediate stage.

INDIRECT SEPARATION

LETTERPRESS	OFFSET	PHOTOGRAVURE
Transparency	Transparency	Transparency
Separations	Separations	Separations
Positives	Positives	Positives
Screen negatives	Screen negatives	Carbon image
Blocks	Positives	Printing cylinder
	Plates	
or	or	or
Colour negative	Colour negative	Colour negative
Positive separations	Positive separation	Positive separation
Screen negatives	Screen negatives	Carbon image
Blocks	Positives	Printing cylinder
	Plates	

See diagram p. 39

PHOTOMETRY

As explained in the section on light, light waves are electro-magnetic in character and consequently possess electro-magnetic energy. Photometry is used to measure this energy. The results of such measurements are influenced by the receiving system. For example, if the receiving system absorbs all electro-magnetic waves, infra-red, visible, and ultra-violet, and measures them by conversion into heat, the results will be different from those obtained with a receiver which absorbs only visible rays and completely ignores the infra-red and ultra-violet. Generally photometric measurements are restricted to the visual rays as these are, subjectively, the most important. This section will therefore be restricted to visual photometry and to photometry using receiving systems whose spectral absorption curve is reasonably close to that of the eye. Such curves are common to most exposure meters and to many photographic materials. The use by most photographers of exposure meters whose spectral response corresponds more or less with that of the eye is reasonably correct when using most panchromatic plates but the ultra-violet region to which all

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

photo-sensitive materials respond is completely ignored by both exposure meter and photographer. To be strictly accurate each photographic material should be used with its own particular type of exposure meter but this is hardly practicable. Measurements must be made by the most convenient photometric system corresponding to the visual response, and adjustments must then be made according to the particular characteristics of the emulsion.

Energy flux Consider a surface S bounded by a line as shown in Fig. 1. The electro-magnetic waves absorbed by the surface S carry a certain magnetic flux to the surface. The energy flux can be compared to power and can be measured in watts.

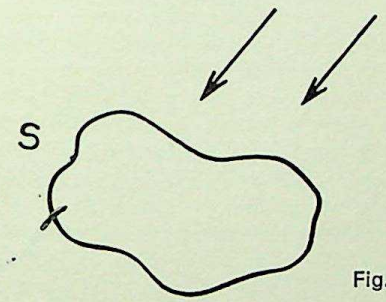


Fig. 1

Luminous flux When viewed under similar conditions, two energy fluxes having the same power and spectral composition will appear identical. They will not however appear the same, even though of similar power if they are monochromatic and of different wavelength as the sensitivity of the eye varies with wavelength. (This is particularly true if one of the radiations is in the ultra-violet or infra-red regions; it would not be visible to the eye, whereas the other radiation would be.)

Experience has shown that two monochromatic fluxes Φ_1 and Φ_2 of wavelength λ_1 and λ_2 can give equal visual impressions except for colour. The relationship $V_{\lambda 1}\ \Phi_1 = V_{\lambda 2}\ \Phi_2$ applies where $V_{\lambda 1}$ and $V_{\lambda 2}$ are characteristic factors of the two wavelengths λ_1 and λ_2 and called relative luminous efficiency or luminosity. The luminous flux can therefore be defined relative to monochromatic light by the following expression: $F = k_m V_\lambda \Phi$ where k_m is a constant depending on the units used to measure F and Φ and where V_λ is made equal to 1 at the wavelength at which it is a maximum. (These points will be considered later.) The product $K_m V_\lambda$ is called the relative luminosity. In other words the relative luminosity at the wavelength under consideration is multiplied by the energy flux to give the luminous flux.

It is generally found with complex radiations that addition of the individual monochromatic energy fluxes gives the total flux according to the expression:

$$F = k_m \int V_\lambda . \phi_\lambda . d\lambda$$

where the product $\phi_\lambda . d\lambda$ represents the energy flux corresponding to the wavelength situated between λ and $\lambda + d\lambda$ and where the integral remains within the wavelengths of the visible spectrum. To correlate the luminous flux with the energy flux (i.e. watts) it is first of all necessary to know the relative luminosity V_λ, in other words the visual spectral sensitivity curve, and secondly to calculate the factor k_m after the luminous flux unit has been calculated.

The visual luminosity curve can be determined quite accurately by one of several methods but varies considerably with individuals and consequently the photometric results are subjective. In 1924 the Fourth International Congress standardized on the curve shown in Fig. 2; this curve applies only to daylight conditions (see Purkinje's effect in the section on Vision). This curve has its maximum of 1 at ·555μ (in the yellow green) and drops to about 0·001 at 0·41μ in the violet and 0·72μ in the far red. These have been taken as the limits of the eye's sensitivity.

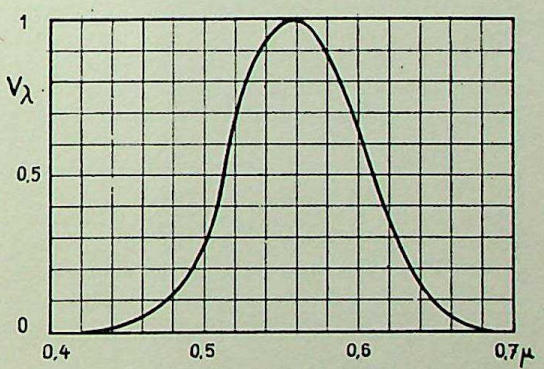


Fig. 2

Using the lumen as the unit of luminous flux and a value of 679 for the coefficient k_m the unit of energy is the watt. One watt of radiation energy will thus give at its maximum a luminous flux of 679 lumens, when the source is monochromatic and has a wavelength of 0·555μ. For all other wavelengths there will be less than 679 lumens per radiated watt.

Illumination Take any point M on a lighted surface (Fig. 3). Around it mark a small area dS and let dF represent the luminous flux received

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

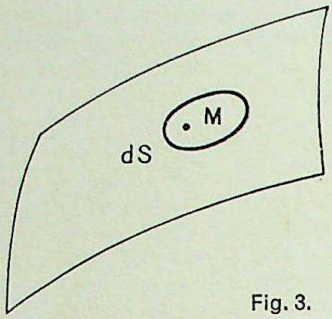


Fig. 3.

by this area dS. The illumination E at point M is the limit of the ratio dF/dS, where dS tends to zero around point M.

As the unit of luminous flux is the lumen, the unit of illumination is the lux (lumens/m²); lumens/cm² or phot is also used: this is equal to 10,000 lumens.

Point source intensity Imagine a sphere Σ having at its centre a light source O which is very small compared with the size of the sphere and can be considered as a point source (Fig. 4).

The illumination E by the source O is constant at all points on the surface of Σ; the source O can then be described as uniform. Generally, however, E varies at different parts of Σ and the emission properties of source O have then to be determined in any direction Ox. This is the object of studying intensity.

Around the line Ox take a cone having its centre at O and subtending a solid angle $d\Omega$. As light is transmitted in straight lines and assuming there is no loss due to atmospheric absorption, there will be no loss of light between the source and the area bounding x. Consequently if the cone is cut at any plane (Fig. 5) the total luminous flux at that plane will be constant in the proportion $dF/d\Omega$. The point source intensity O in the direction Ox is then defined as the limit of the proportion $dF/d\Omega$ when $d\Omega$ tends to zero around the axis Ox.

With the lumen as the luminous flux unit, the unit of intensity is the lumen per steradian; this was originally called a candle, but the term candela is now used.

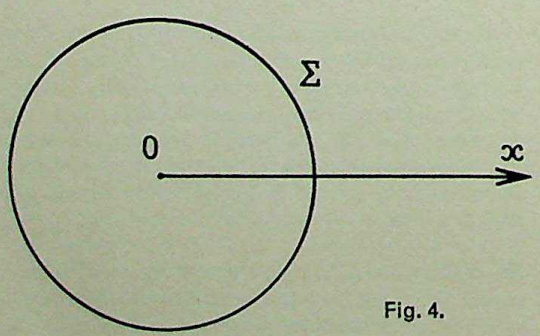


Fig. 4.

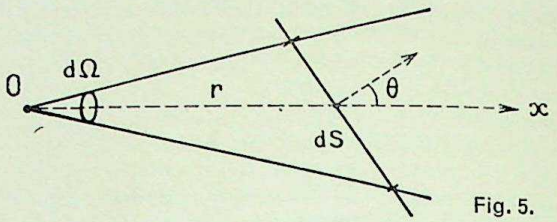


Fig. 5.

If the angle between the perpendicular to dS and Ox is θ, and r the distance from O to point dS, then according to the definition of the solid angle,

$$d\Omega = \frac{dS.\cos\theta}{r^2}.$$

Therefore

$$I = \frac{dF}{d\Omega} = \frac{dF.r^2}{dS.\cos\theta}.$$

As the ratio dF/dS determines the illumination E on area dS it follows that:

$$I = E\frac{r^2}{\cos\theta} \text{ or } E = \frac{I\cos\theta}{r^2}$$

The illumination therefore varies inversely with the square of the distance from the source; this is governed by the laws of conservation of energy (dF remains in the cone while dS varies with r^2). This law breaks down in an absorbing medium — for example when taking photographs under water with artificial light.

Starting with the relationship $E = dF/dS$ or $E = I/r^2$ (assuming θ to be zero) the illumination in lux by definition is equal to 1 lumen/m² and also by 1 candela at a distance of 1 m., the screen being perpendicular to the axis between itself and the source.

Emission of a finite light source In the case of sources of finite area, the word intensity cannot strictly be used; the emission at any point must be defined in two ways. Either the total emission in all directions can be measured or measurement can be confined to a restricted region.

Take an area dS around point O on the surface of our previously considered receiving surface (Fig. 6). Now take the luminous flux dF emitted through area dS in all directions, that is through an angle of 2π steradians situated on the exterior tangential surface having its centre at O. The total emission of O is the limit of the ratio dF/dS as dS tends to zero. Like illumination, brightness can be measured in lumens per m² but with the difference that illumination is received energy whereas brightness is emitted energy.

Let the light passing from O in the direction Ox be isolated by means of an opaque screen perpendicular to Ox having an aperture $d\sigma$. With the diaphragm in position the intensity of the light

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

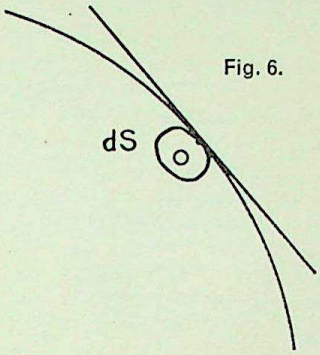


Fig. 6.

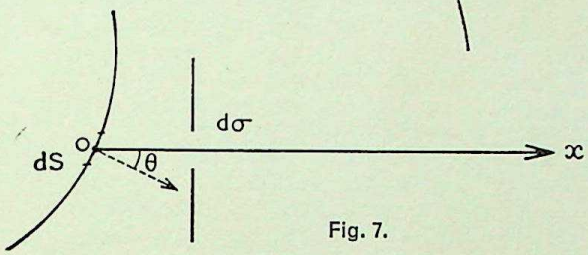


Fig. 7.

in direction Ox is dl.

The relationship dl/dσ where dσ tends to zero gives the luminance (previously called brightness) of the light source O in the direction Ox.

Whereas emissive power essentially involves a receiving surface around a light source, luminance can be applied to luminous three-dimensional objects such as the sky. An observer situated at x looking through the aperture dσ will see an area dS of the light source where $d\sigma = dS.\cos\theta$ (θ is the angle between the line Ox and the normal to the surface at O). The area behaves as a secondary light source (corresponding to dS); luminous power can therefore be expressed as the ratio of the intensity at this point relative to the area dσ when the latter tends to zero but this conception requires a defined external surface.

The unit of luminous power is the candela/m² or candle/m². Sometimes the term stilb or candela/cm² is used; this is equal to 10,000 candela/m².

To sum up we have the following units:

Luminous flux	lumen
illumination	lux
intensity	the candela
brilliance	the candela/m²

The first unit of intensity was the International Candle and was related to standardized electric lamps. In 1948 a more well defined unit was established, first called the New Candle and then the Candela. It is defined by the statement that 1 sq. cm. of a black body radiator at the temperature of freezing platinum has a luminous intensity of 58·9 International Candle or 60 Candela. The Candela is therefore 0·98 International Candle. The standard unit is that of intensity and all others are related to it. To determine the factor k_m, the starting point is the definition of luminous flux and knowing that the intensity of a black body at the freezing point of platinum is 60 candela/cm² and that the unit of energy flux is the watt, it follows that $k_m = 679$.

Photographic applications Consider a plane dS situated away from the lens axis having an area dσ which behaves as a secondary source when seen through the lens; $d\sigma = dS.\cos\alpha$ (α being the angle between the plane of dS and the lens principal axis). Let L be the intensity in the direction of the camera (Fig. 8). By the definition of intensity the small area dS can be considered as a point source with an intensity of $I = L.d\sigma = L.dS.\cos\alpha$ in the direction of the camera and will therefore send to the camera a luminous flux of

$$F = I.d\Omega = L.dS.\cos\alpha.d\Omega \ldots\ldots (1)$$

where $d\Omega$ is the solid angle of the cone having as its base the entrance pupil of the lens and the point source as apex. Let Σ be the area of the entrance pupil of the lens and r be the distance from Σ to the point source, then:

$$d\Omega = \frac{\Sigma \cos\alpha}{r^2}$$

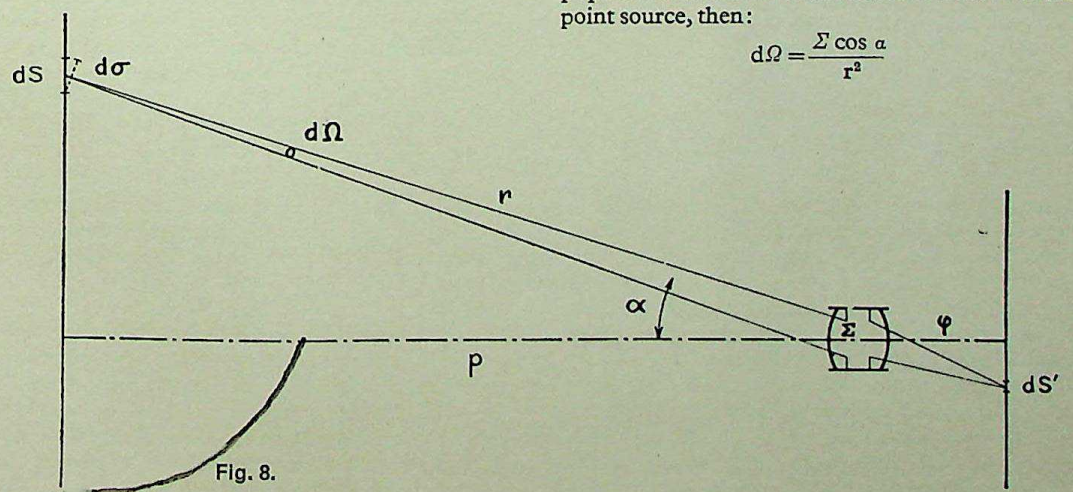


Fig. 8.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

or as we know that $r = p/\cos\alpha$ (p being the distance to the entrance pupil or subject distance),

$$d\Omega = \frac{\Sigma.\cos^3\alpha}{p^2}$$

Here we can replace $d\Omega$ in equation (1) and we find that the light emitted to the camera by the small area dS is:

$F = L.dS.\cos\alpha.\Sigma.\cos^3\alpha/p^2 = L.dS.\Sigma.\cos^4\alpha\ p^2$

During its passage through the lens the luminous flux suffers some loss by reflection, absorption and diffusion and becomes

$$F' = t.F = t.L.dS.\Sigma.\cos^4\alpha/p^2$$

where t is the transmission factor of the lens.

The luminous flux F′ is distributed over the image dS′ of the object dS; at that point the incident light on the image will be

$$E = F'/dS' = t.L.dS/dS'.\Sigma.\cos^4\alpha/p^2 \ldots (2)$$

The proportion dS′/dS is equal to the square of the magnification. If the subject is sufficiently distant and correctly focused the magnification will be ϕ/p, where ϕ is the focal length of the lens. In equation (2) dS/dS′ can now be replaced by p^2/ϕ^2 giving

$$E = t.L.\cos^4\alpha.\Sigma/\phi^2$$

$\Sigma = \pi O^2/4$, where O is the diameter of the entrance pupil.

This finally gives

$$E = \frac{\pi}{4}.t.L.\left(\frac{O}{\phi}\right)^2.\cos^4\alpha$$

The illumination on the surface of the sensitive material depends on the light reflected by the particular portion of the subject's surface and upon the square of the relative aperture of the lens. Disregarding other factors the image illumination decreases from the centre to the edge of the field of view in the proportion $\cos^4\alpha$; this takes into account the decrease in the apparent area of the subject, the decrease in the apparent area of the entry pupil, and the increase of the oblique distance r from lens to subject. The above calculations apply when the subject distance is great compared with the focal length. In close-up work the brightness of dS′ decreases and must be adjusted by increasing the aperture or the exposure time. The necessary factors can be most easily obtained from tables. In macrophotography when appreciable lens extensions are involved this error can be considerable. On the other hand, if a supplementary lens is used instead of increasing the lens extension, the effective aperture of the lens is increased and provided no excessive extension is involved, no exposure correction need be applied.

From this it can be seen that to the photographer the most important factor is the brightness of the subject, or more accurately the brightness of all parts of the subject in the field of view. For exact agreement with the brightness units specified above the colour sensitivity of the photographic material must be comparable with that of the eye. In practice, particularly with colour materials, variations are experienced which are very difficult to estimate. Some types of exposure meter are in fact visual photometers and are capable of measuring small subject area by comparison with a standard area. Such meters can give very satisfactory highlight or shadow readings with neutral subjects but assessment is very difficult if the subject is strongly coloured as the eye cannot readily match the luminance of a colour and a neutral. The common method, however, is to use a photo-electric cell which gives an integrated reading of the whole range of subject brightness falling within the field of view. At low light levels the cell must be put into the subject position and pointed towards the camera so that it receives the incident light rather than measuring the reflected light. A correction factor must then be applied depending on the nature of the subject.

Reflected light readings are essentially related to average subjects and give satisfactory results only as long as the subjects reflection characteristics are close to average. For more precise results the use of a photometer or incident light meter is strongly recommended particularly for colour work where the emulsions have far less latitude than those used for black-and-white.

PINATYPE

When a bichromate impregnated gelatin layer is exposed behind a negative the unprotected areas which are exposed are hardened whilst the protected unexposed areas retain their solubility in water. Washing in water removes the salts from the unexposed areas and an almost invisible image in hard and soft gelatin remains.

When such a layer is immersed in a solution of an acid dye, only the soft parts take up the solution. By pressing a sheet of gelatin-coated paper against the dyed layer (both being moist) the dye will be transferred to the layer on the paper giving a reversed image of the original. Working from a negative, a negative image will be obtained, so for positive print a transparency or diapositive must be used.

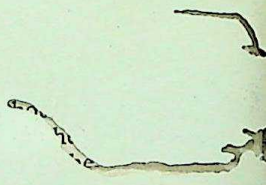
Three-colour process By means of three plates prepared in the way described, a three-colour paper print can be produced. Each printing plate is exposed behind a positive made from one of a set of three separation negatives. The plates are dyed in solutions of complementary colour to the filter used to make the separation negatives.

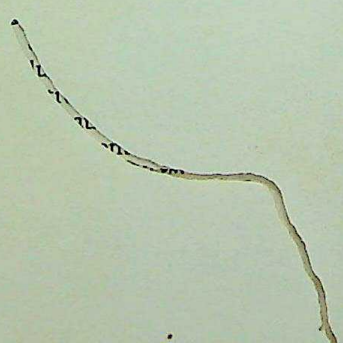
CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

THE WINDOW BOX

Photo : W. Schmölcke (Gevacolor reversal film)

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh





CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Although the Pinatype process is relatively straightforward the sensitivity of a bichromate sensitized layer is so low that daylight or an arc lamp must be used to obtain the required intensity. Commercial application in recent years has been restricted to Chimicolor and Supercinecolor.

POLARIZATION

THE USE OF POLARIZING FILTERS IN COLOUR PHOTOGRAPHY

Polarizing filters are simple to use and can give photographic effects which are not obtainable by any other means.

Polarization takes place in the following way: a normal luminous source, an electric lamp for example, emits light which is not polarized. It can be pictured as a vibration taking place in all directions around the axis of the beam of light. When such a beam is reflected by a polished metallic surface (specular reflection) or by a completely matt non-metallic surface (diffuse reflection), the reflected light is also unpolarized.

If the light beam is reflected obliquely from a glass surface the reflected beam will not contain an equal distribution of light vibrating in all directions. It will contain a greater proportion of polarized light vibrating in one direction only. If the angle of incidence is 57° polarization will be virtually complete. Most surfaces are to some extent polarizing in the effect they have on reflected light. The non-polarized component is made up of light which penetrates the surface layer of the object where it is diffused and partially absorbed before re-emission; it is this part which gives an object its colour.

These polarizing effects can be reproduced by means of polarizing filters which only pass light vibrating in one plane. This plane is usually indicated on the filter mount. If two polarizing filters are placed one above the other with their polarization planes at right angles, no light will pass through; they are then said to be in 'extinction.' On the other hand if the two filters are placed with their polarization planes parallel the maximum amount of light will be transmitted; the losses produced by the second filter being relatively small. Polarizing filters can be used singly or in pairs as in the following example. One polarizing filter is placed over a spotlamp lighting a glossy surface whilst the other is placed over the camera lens. Some of the light reflected by the glossy surface will be polarized and will appear as a reflection which can be eliminated by suitable orientation of the camera. The remainder of the light reflected will not be polarized and will show the colour and other characteristics beneath the glossy surface irrespective of the position of the camera filter.

If the light reflected by a glossy non-metallic surface falls within a certain angular range, it will be polarized even without a polarizing filter over the light source.

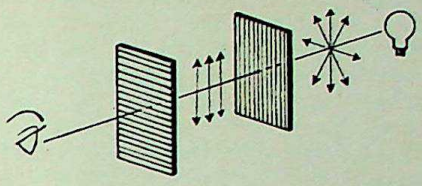


Fig. 1.

Two crossed polarizers: no light passes and the source is invisible to the observer.

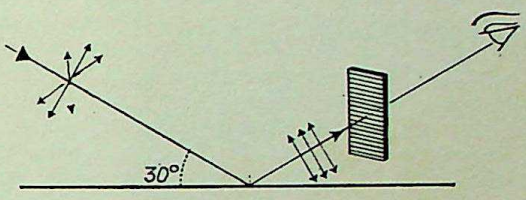


Fig. 2.

Light reflected at 30–35° from non-metallic surfaces is polarized by reflection.

APPLICATIONS

Exterior colour photography When photographers using black-and-white materials wish to darken a blue sky or to increase the contrast between the blue sky and white clouds they use one of a range of yellow to red filters according to the degree of darkening required. Obviously this means of control is not available to the colour photographer but some degree of darkening of the sky without altering the colour balance can often be achieved by use of a polarizing filter. The greatest effect is when the sun is at right angles to the direction of view and the effect can readily be gauged by rotating the filter in front of the eye until the required darkening is obtained and then slipping the filter over the lens in the same angular position. Polarizing filters are also of great use in cutting down reflections from polished or other highly reflecting surfaces such as water.

By cutting down glare from specular reflecting surfaces, polarizing filters can give an apparent increase in contrast which is often so startling that the scene itself appears to have changed. The polarizing filter itself absorbs light and as it has a darkening tendency (as far as shadows are concerned) an appreciable exposure increase is necessary — in the region of three to four times for landscape work.

In the studio The combination of a polarizing filter over the light source and one over the lens is

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

extremely useful when copying flat opaque originals. The obvious benefit is the elimination of surface reflections from all types of flat copy but when dealing with pencil and crayon drawings where reflection from the minute graphite and wax particles can cause appreciable loss of contrast this reflection elimination is accompanied by a considerable increase in saturation.

This system can also be used for photographing paintings. When two polarizing filters are used together in this way exposure times must be greatly increased, particularly if the orientation of the two filters is such that they are close to the point of extinction.

In commercial work involving the photography of wood and glass objects, the use of polarizing filters is useful in eliminating surface reflections without altering the colour reproduction.

For work of the highest accuracy it must be remembered that commercial polarizing filters are far from perfect. They usually pass a small proportion of unpolarized light in either the blue or red spectral regions; secondly they are made of plastic and although suitable for use over light sources are not perfect enough optically for camera use where a high standard is required. They can be cemented between pieces of optical glass to improve their characteristics; even this does not make them suitable for work of the highest precision.

PORTRAITURE IN COLOUR

In black-and-white portraiture special lighting arrangements are frequently used to obtain particular effects. Such lighting arrangements almost invariably involve high lighting contrasts to achieve their end. In colour portraiture on the other hand a more subtle approach must be made. A portrait is not simply of a person surrounded by various objects; the sitter is the centre of interest and the surroundings should not distract the attention.

Irrespective of whether portraits are taken in daylight or artificial light, flesh tints, whether light and transparent or deeply tanned, must be correctly rendered.

A photographer who is experienced in black-and-white portraiture will be able to forget the composition problems common to black-and-white and colour work, and devote his attention to the new problems of colour portraiture.

Outdoor portraiture In true outdoor portraiture all objects other than the sitter should have their importance suppressed as far as possible, preferably by putting them into an out-of-focus background. Ideally the background should be a substantially even area. The blue sky is a very good background for portraits partly because of its undefined form and partly because of the excellent colour contrast of blue with the skin; this is far less distracting than the contrast of flesh colours against green foliage or grass.

Not only should the colour of the background be suitable, but detail must be suppressed by judicious control of depth of field either in focusing by placing the subject as far as possible from the background, or by using a larger lens aperture.

With a dark background the lighter skin-tones will tend to stand out in bold relief and underexposure of a dark background is unimportant provided that the sitter is correctly exposed. The use of a doorway as a frame and background is extremely effective in this way. A medium toned background should be of a colour which contrasts with the skin colour and rather more contrasty lighting must be used to make the subject stand out. Light backgrounds are the most difficult to use successfully. They are more suitable for use with darker-skinned or sunburnt models.

A white sunlit wall will tend to be over-exposed and if the exposure estimation is based upon the subject the wall will probably be reproduced as a completely clear area on the transparency. If such a wall is in shade it will pick up a certain amount of blue from the sky, or other slight colour cast from neighbouring strong colours. This darkening will be an improvement with such a background. It is vital however that the subject should receive no strongly coloured reflected light. When removing such reflections the tendency to have warm highlights and cold shadows in exterior portraits should be noted.

A subject lit by midday sun from a clear sky will have areas receiving the total sunlight plus skylight correctly reproduced; highlight areas receiving only direct sunlight and shielded from the majority of the sky will tend to be warm whilst the opposite areas lit only by the sky light will be far too blue. This gives a natural plastic effect which can become complicated by warm toned shadows which may be obtained by the use of a second light source or unsuitable reflector, although this additional light source may be desirable for other reasons. The best type of reflector to use for lightening the shadows and reducing contrast is a very large sheet of white paper reflecting light into the shadows from the brightest part of the sky.

Indoor portraiture

Daylight Daylight portraits can be taken indoors in a well-lit room provided there are plenty of light-coloured reflecting surfaces which reduce

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

contrast. Great care must be taken when placing a sitter near a window and the use of reflectors to reduce lighting contrast is essential.

Compared with exterior portraits, exposures required indoors are greatly increased but are still reasonable with the subject 4 to 6 ft. from a window.

Direct sunlight entering the window would give uncontrollably high contrast for portraits, therefore only diffused sky light may be used. If this is too blue a Wratten 1A correction filter should be used as in outdoor work.

Special care must be taken with nearby coloured objects which can cast coloured reflections into the shadows.

As a general rule, the background must be moderately lit and darker than the shadows of the face. It is extremely difficult to have a well-lit background without using a second light source. With a second light source difficulties may be encountered when using a mixture of daylight and artificial light, though both blue flashbulbs and electronic flash are suitable.

Artificial light As snapshot exposures are not essential for portraiture a choice can be made between using photoflood lamps (3,400°K) or studio lamps (3,200°K) with film balanced to suit the light source chosen. The colour portrait photographer needs more lamps than does the black-and-white photographer; in the latter case very striking though contrasty effects can be obtained by the use of a single spotlight. The same type of effect can be attempted in colour work but success is usually fortuitous. Only personal taste can govern the choice of lighting and colour contrast but it should be remembered that with colour materials, both reversal and negative, the exposure latitude is relatively low and a lighting contrast exceeding 4:1 runs the risk of incorrect colour reproduction in either shadows or highlights or both. In practice a contrast as low as 2:1 is desirable. It is therefore essential to use several lamps of the same colour temperature and as far as possible having had the same amount of use. Spotlight lenses or diffusers should not alter the colour temperature (see Artificial Light); they are used either to flatten the lighting by filling in the shadows or to accentuate a particular area by highlighting it.

The simple black-and-white system of two light sources is a good basis for starting work in colour photography. A spotlight or reflector lamp usually forms the key light placed at an angle of 45° to a line between the camera and the subject slightly above the sitter's head; this gives a very hard lighting and used alone is unsuitable for colour work. A second lamp must be used to light up the shadows; it should be placed in a large area reflector and is situated as near as possible to the camera position so that it casts no visible shadows. Exposure meter readings on highlight and shadow areas tell whether any movement of key light or fill-in is necessary to bring the lighting ratio within the 2 : 1 range. The contrast reduction can also be achieved with sheets of white reflecting material. Large reflectors and camera position fill-in lamps are the only means of reducing subject contrast without increasing the number of unwanted shadows; each lamp (apart from that in the camera position) produces a shadow.

When only two lamps are used the background will tend to be under-exposed as both lamps will be required to light the subject. The background colour will probably be distorted. A third light source situated behind the model or at the side, out of the camera's field of view, will lighten the background, bringing it back to its correct depth and giving a better general balance. In this case the background can be further away and can therefore be thrown out of focus giving a general tint rather than a well-defined region.

Finally a back-light placed behind the sitter can be used to produce a slight halo effect which will make the model stand out from the background; this lamp should be used discreetly so that the lighting balance is not exaggerated.

Exposure time Exact colour reproduction can only be obtained by giving correct exposures determined with an exposure meter. The exposure should be determined by highlight measurements on the model and by keeping the lighting ratio within the recommended 2:1 range. The highlight measurement must be made with great care so that when the cell is measuring one area it is not influenced by adjacent areas of different brightness. The white card method (see Exposure) is often recommended but it must be remembered that the resulting calculated exposure must be multiplied by 5. To obtain good colour rendering on the background the latter must generally be illuminated by its own spotlamp which is separately adjusted within the 2:1 range relative to the subject.

The colour of the surroundings in a portrait are of aesthetic rather than technical importance; this is particularly true of the background where colour harmony must be achieved. A colour impression will be reduced if more intense colours are adjacent to it and on the contrary will be increased if less intense colours are adjacent to it. Two different colours of the same intensity will lose impact. For example, a correctly rendered skin hue will seem lighter and less coloured on a black background than on a white one. As in painting, the judicious use of neutrals can bring distinction to colour photographs by blending otherwise unsympathetic colours.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

POSITIVE-POSITIVE PRINTING

Many of the observations in the section on negative-positive system (q.v.) are also applicable to positive-positive printing although there are a number of differences in procedures between the two methods. Positive-positive printing is carried out using duplicating film of the Anscochrome or Kodachrome type or an opaque base material such as Ansco Printon and Ilford colour print stock which have white plastic base or Kodak Type R paper which has a paper base. It should also be noted that any transparency such as Kodachrome, Ektachrome, Anscochrome, etc, can be printed using an inter-negative and ordinary positive paper as follows:

TRANSPARENCY → Internegative → large size transparencies
Internegative → positive paper
Internegative → same size transparencies

Printing methods Both additive and subtractive printing systems can be used.

Grading This stage is obviously much simpler than in the case of negative grading. Very little training is required to judge visually any colour cast present in a transparency and to assess the degree of correction required. It must be noted that all filtration is reversed compared with the negative-positive system due to the use of a reversal process.

Original	*Correction required*
Light	Under-expose
Normal	Normal printing
Dense	Over-expose
Neutral	Normal printing
Cyan	Add red filter
Magenta	Add green filter
Yellow	Add blue filter
Green	Add magenta filter
Blue	Add yellow filter
Red	Add cyan filter

The same table can also be used as guide to the correction required when judging a trial print.

Printing equipment It may seem that the complex grading equipment used for negative-positive printing is not necessary for positive-positive printing in view of the relative ease of grading but the advantages of fully automatic systems are so great that they should be considered whenever a large output of prints is required.

PRINTING PROCESSES: NEGATIVE-POSITIVE

AGFACOLOR, FERRANIACOLOR AND TELCOLOR PROCESSES

In broad terms the printing methods used for Agfacolor, Ferraniacolor and Telcolor are so similar that they can be considered under the same heading.

As a colour negative may be under-exposed, over-exposed or out of balance, the steps involved are:

(*a*) Determination of the exposure time for the negative.
(*b*) Assessment of the filter or filter combination required to correct any colour cast.
(*c*) Further correction of exposure to compensate for the addition of correction filters.

Equipment Any good quality enlarger suitable for black-and-white work can be used for colour printing provided that:

1. It is light-tight.
2. It has a good quality lens, preferably coated.
3. Some method of holding filters such as a filter drawer which is preferably located between the light source and condenser so that any light reaching the negative must have passed through the filter.

Filters It is preferable to use the filters supplied by the manufacturer for the particular brand of paper which is used. Each manufacturer provides a set of eleven filters in each of the three colours although the values are not necessarily the same for each brand.

Practical procedure The first step is to estimate the exposure time from the general negative density ignoring any colour discrepancy. As in the test printing of black-and-white negatives to determine the correct grade of paper, a number of trials may be needed. The first test print which has the correct density will generally not be satisfactory from the colour point of view. All enlargers have their own colour characteristics due to the characteristics of the particular lamp and to all reflectors and optical components which take part in illuminating the negative or producing the baseboard image.

Compared with the correct colour printing light, an excess of blue in the actual light used will give a yellow print as the green- and red-sensitive layers will be relatively under-exposed and the blue-sensitive layer which produces the yellow image will receive excessive exposure. It is, therefore, necessary to filter the exposure light. As the colour cast is due to over-exposure of one particular layer the light reaching that layer must be reduced to obtain a correct print and the filter to use in reducing light of that particular colour is a

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

filter of the same colour as the colour cast. All colour casts must be eliminated in this way whether due to the printing equipment or to negatives of incorrect balance.

A cyan cast is eliminated with a cyan filter, a magenta cast with a magenta filter and a yellow cast with a yellow filter. Similarly a red cast is corrected with magenta plus yellow filters, green with cyan plus yellow and blue with cyan plus magenta. It is never necessary to use more than two differently coloured filters; the use of a third filter will only increase the neutral density and so lengthen the exposure required. It is not enough to know the colour of the filter required, the strength of the filter must also be determined. Each colour is supplied in steps of 10, 20, 30, 40, 50, 99, 99, with an additional 05 for finer corrections to avoid doubling the number of filters. A complete set of twenty-four filters is therefore required.

The requisite filters to correct the colour balance are estimated for the second step and the third is to multiply the exposure required without filters by a correction factor which compensates for the light absorption of the filters. The yellow filter requires little change from one density to another. A factor of 1·2 can be used for all densities of yellow filters, the main loss of light being due to reflection at the filter surface.

To denote the filters required a six digit group is used, 00, 00, 00. The first pair corresponds to yellow, the second to magenta and the third to cyan. Therefore 50, 00, 20 indicates a combination of a yellow filter density 50 together with a cyan filter density 20. If only the last filter were used it would be denoted by 00, 00, 20.

The increase in exposure is calculated according to the absorption factor of each filter which can be expressed as a factor by which the standard exposure is multiplied. To avoid calculations the accompanying tables show the exposure increase required for various filters used with each process.

Use of the table Take for example, 20, 40, 00; at the intersection of the yellow filter column with that for 40 magenta will be found the factor 1·6. Thus for a basic exposure of 5 sec. the modified exposure necessary when adding 20Y and 40M will be $1{\cdot}6 \times 5 = 8$ sec.

The combination 00, 20, 30 will require an increase to 1·9 times the basic exposure, the factor being obtained at the intersection of 20 magenta and 30 cyan. If only one magenta or cyan filter is used, the reading is made for magenta in the second vertical column and in the second horizontal column for cyan. All the yellow filter densities require a constant exposure factor of 1·2. The use of a supplementary 05 filter of any colour

Coefficients of Agfacolor Filters

			10	20	30	40	50	60	70	80	90	99	
		Cyan→	1·3	1·4	1·5	1·6	1·8	1·9	2·1	2·3	2·5	2·7	Yellow + cyan
Yellow→ Magenta↓		1·2	1·5	1·6	1·8	1·9	2·1	2·3	2·5	2·7	2·9	3·2	
10	1·2	1·4	1·6	1·7	1·9	2·0	2·2	2·4	2·6	2·8	3·1	3·3	
20	1·3	1·5	1·6	1·8	1·9	2·1	2·3	2·5	2·7	2·9	3·2	3·5	
30	1·3	1·6	1·7	1·9	2·0	2·2	2·4	2·6	2·8	3·1	3·3	3·6	
40	1·4	1·6	1·8	1·9	2·1	2·3	2·5	2·7	2·9	3·2	3·5	3·8	
50	1·5	1·7	1·9	2·0	2·2	2·4	2·6	2·8	3·1	3·3	3·6	3·9	Magenta + cyan
60	1·5	1·8	1·9	2·1	2·3	2·5	2·7	2·9	3·2	3·5	3·8	4·1	
70	1·6	1·9	2·0	2·2	2·4	2·6	2·8	3·1	3·3	3·6	3·9	4·3	
80	1·6	1·9	2·1	2·3	2·5	2·7	2·9	3·2	3·5	3·8	4·1	4·4	
90	1·7	2·0	2·2	2·4	2·6	2·8	3·1	3·3	3·6	3·9	4·3	4·6	
99	1·8	2·1	2·3	2·5	2·7	2·9	3·2	3·5	3·8	4·1	4·4	4·8	

Yellow + magenta

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Coefficients of Ferraniacolor Filters

			10	20	30	40	50	60	70	80	90	100	
		Cyan→	1·3	1·4	1·6	1·7	1·9	2·1	2·3	2·5	2·8	3·0	Yellow + cyan
Magenta↓		Yellow→ 1·2	1·6	1·7	1·9	2·1	2·3	2·5	2·7	3·0	3·3	3·6	
10	1·25	1·5	1·65	1·8	2·0	2·2	2·4	2·6	2·85	3·15	3·45	3·8	
20	1·3	1·6	1·7	1·9	2·1	2·3	2·5	2·7	3·0	3·3	3·6	4·0	
30	1·35	1·65	1·8	2·0	2·2	2·4	2·6	2·85	3·15	3·45	3.8	4·2	
40	1·4	1·7	1·9	2·1	2·3	2·5	2·7	3·0	3·3	3·6	4·0	4·4	
50	1·5	1·8	2·0	2·2	2·4	2·6	2·85	3·15	3·4	3·8	4·2	4·6	Magenta + cyan
60	1·55	1·9	2·1	2·3	2·5	2·7	3·0	3·3	3·6	4·0	4·4	4·8	
70	1·65	2·0	2·2	2·4	2·6	2·85	3·15	3·45	3·8	4·2	4·6	5·05	
80	1·75	2·1	2·3	2·5	2·7	3·0	3·3	3·6	4·0	4·4	4·8	5·3	
90	1·85	2·2	2·4	2·6	2·85	3·15	3·45	3·8	4·2	4·6	5·05	5·55	
100	1·95	2·3	2·5	2·7	3·0	3·3	3·6	4·0	4·4	4·8	5·3	5·8	

Yellow + magenta

will also require a 20 per cent exposure increase.

Ferrania filter factors This table is used in the same way as the Agfacolor table. For a supplementary filter of 05 the factor given in the table must be multiplied by 1·2 (20 per cent). For example, with the filters 20, 00, 45 the factor for 20, 00, 40, i.e. 2·1, is multiplied by 1·2, giving 2·5.

Telcolor filter factors The Telco filters have values of 05, 10, 15, 20, 25, 30, 35, 40, 45, 50, 100; the values between 50 and 100 being obtained by the use of two filters and an extension up to 150 being possible. Clear gelatin filters equivalent to 00 are also provided so that the number of filters in the pack can be kept constant, thus eliminating some of the corrections required when the number of filters is changed. As there must always be three filters in the pack, a correction pack of only two filters will require an 00 filter in addition. If only one correction filter is required then two colourless 00 filters should be inserted whilst the use of three correction filters makes the 00 filter unnecessary.

40 00 10 → two filters plus one 00
20 00 00 → one filter plus two 00
40 60 → three filters

Calculation of exposure time Firstly the filter density is calculated by adding up the equivalent density of each filter; yellow filters are ignored, magenta filters are calculated at half their value and cyan filters at their full value. A filter combination of 00, 40, 10 will therefore have an equivalent of 20 (half 40) plus 10 (full value) = 30.

By referring to the table the multiplying factor corresponding to the filter sum can be read directly.

Over-correction In all cases where a colour cast is corrected by the addition of filters, it is possible to over-correct and produce a cast of complementary colour to that which was first obtained; yellow if the first was blue, green if it

Table of equivalents

Filter value.....	00	10	20	30	40	50	60	70	80	90
Exposure factor.....	1·0	1·1	1·2	1·3	1·4	1·6	1·7	1·9	2·1	2·3

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

PROCESSING WITH AGFACOLOR KIT

STEP	TIME	TEMP.
Agfacolor Paper Developer Pa.I/60	5 min.	65°F
Wash	5 min.	55–68°F
Bleach Fix PPA.III	8 min.	55–68°F
Wash	10 min.	55–68°F
Hardening Bath	5 min.	55–68°F
Wash	5 min.	55–68°F
Buffer Bath PA.IV	5 min.	55–68°F
Wash	5 min.	55–68°F
Anti-fading Bath PA.VI	5 min.	55–68°F

was magenta, etc. So a print with a cyan cast, reprinted with 00, 00, 70 may give a second print with a red cast. To eliminate this red cast the rule is to add red filters, for example:

	00	00	70
plus	10	10	00
=	10	10	70

This combination is equal to 00, 00, 60 plus 10 neutral; as the use of three filters should as far as possible be avoided, the pack is simplified to 00, 00, 60 with the exposure reduced to compensate for the 10 neutral which has been removed.

Agfacolor mosaic filters To avoid tedious testing and waste of sensitive material, Agfa produced a filter mosaic which would give a large number of different filter combinations on the same test print, allowing the correct one to be easily and quickly selected. This mosaic is of chessboard pattern, having thirty-six square elements either in variations of one colour or of one colour combined with a second. The interval between the different steps in these mosaics is 20, i.e., 00, 20, 40, 60, 80, 99, for single filtrations as well as for filter combinations. Of the thirty-six elements one is colourless and therefore of no filter value. Each mosaic filter, having the size of 6·5 × 12 cm., has the same filter chessboard pattern repeated eight times and the effect of a particular filter combination can therefore be seen in different areas of the print. This examination is further simplified by the use of a mask which has eight holes punched in it, each of which corresponds to the same filter combination on each of the different filter mosaics. When making the test this mosaic is laid on the paper so that the colourless square is in the top left hand corner and the exposure time must be doubled compared with exposures made without the mosaic. The use of this mosaic enables the required filter to be estimated quickly and with certainty; the values between the 20 interval of the mosaic can readily be assessed.

Processing of Agfacolor paper As the Agfacolor paper is panchromatic both printing and processing should be carried out in the dark. However, an Agfa olive-green filter No. 166 fitted to a safelight having a 15-watt bulb can be used, provided the lamp is no closer than 3 ft. to the workbench. Development time has some effect on the image contrast; an increase in development time is recommended when dealing with flat under-exposed negatives.

When prints are to be drum-dried an Agfacolor hardener must be used after the second wash.

FERRANIACOLOR PAPER PROCESSING
using Ferrania kits

	STAGE	NOTES	TEMP.	TIME in min.
1	Colour development	5 min. development gives contrasty prints	65°F ± ½°	3–5
2	Wash	Thorough, in running water	65°F max.	15
3	Bleach-fix		60–65°F	10
4	Wash	Thorough, in running water White light may be used	65°F	15
5	Stabilizer	Increases stability and permits drying or glazing up to 176°F		8
6	Drying	Warm drying (158°F to 194°F) only if stabilizer was used		

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

TELCOLOR PAPER PROCESSING
using Telco kit

	STAGE	NOTES	TEMP.	TIME in min.
1	Colour development		65°F	3
2	Wash	In running water	65°F	10
3	Bleach-fix	Normal roomlight	65°F	6
4	Wash	Thorough washing in running water	65°F	20
5	Dry		95°F max.	

PRINTING PROCESSES: POSITIVE-POSITIVE

ANSCOCHROME PRINTON PROCESSING

Anscochrome Printon, which has succeeded Anscocolor Printon, is a white plastic-based material for making reversal prints from Anscochrome or similar transparencies. Printon has the same structure as reversal film; three emulsion layers are coated on an opaque cellulose ester base. Printing can be carried out by contact or in an enlarger and normal black-and-white equipment can readily be adapted (see negative-positive printing).

Quality of the transparency Only first-class transparencies should be used for making Printon prints; whilst it is possible to correct slight errors in colour balance when printing, a general lack of quality will only lead to unsatisfactory prints in which there is no colour saturation. On the other hand, contrasty transparencies should be avoided for although they might be quite satisfactory for projection it will not be possible to reproduce both shadows and highlights satisfactorily in the print.

Printing procedure The main difference between Printon printing and printing from colour negatives is in the processing of the Printon material. The main equipment requirements are a set of compensating filters, an Ansco 16 ultra-violet absorber and an Ansco heat-absorbing filter. A lamp should be used whose colour temperature is approximately 3,000°K, but to correct for peculiarities of the equipment or variations in the batch of stock some filtration will be necessary.

The first step is to determine the exposure time using the test material which is included with each packet of Printon. The ultra-violet absorber, the heat-absorbing filter and the correction filter recommended with the batch of stock should be fitted into the enlarger.

To avoid wastage of test material only a small area should be used for each test. The preliminary test can be made after adjusting the enlarger in the normal way by giving exposures equal to 2, 4, 8 and 16 times that which would be given to normal bromide paper under similar conditions but without the filters. It should be remembered that as Printon is a reversal material, increasing exposure will lighten the result. If the test strip shows no colour cast the final print is made using the appropriate exposure time.

Filtration Ansco colour filters for printing are made in varying densities of yellow, magenta and cyan.

Yellow: 23, 24, 25, 26
Magenta: 33, 34, 35, 36
Cyan: 43, 44, 45

The filters increase in density with a factor of 2; that is each filter is double the density of the preceding one and half the density of the succeeding one. Thus a yellow 24 has twice the density of the 23 and half the density of 25. It has already been explained that the filtration rules for positive-positive printing are the reverse of those for negative-positive printing. The colour of the filter used will be reproduced on the print. A colour cast must therefore be eliminated by the use of the complementary colour or alternatively a lack of one colour is compensated by adding filters of the colour required. The exposure time must be corrected according to the filters which are used. The factors are 1·1 for filters 23, 33, and 43; 1·2 for 24, 34, and 44; 1·4 for filters 23, 35, 45, and 1·8 for filters 26 and 36. The reciprocal of these factors is used when filters are removed to correct a colour cast.

Example: The correct exposure using the filter No. 34 recommended for the batch is 20 sec. at the required magnification and aperture but the resulting print is too magenta. The magenta filter is removed and the exposure is reduced to $20 \times 1/1{\cdot}2 = 16{\cdot}6$ sec. If the test was made without a filter the magenta cast is eliminated by adding green, i.e. 24 yellow plus 44 cyan, and the exposure is increased by a factor of 1·4; $20 \times 1{\cdot}4 = 28$ sec. A flat copy print cannot reproduce all

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

the colour of the original transparency but the main difference will be seen in terms of brightness rather than hue. If the print contains white or neutral areas colour casts will be made apparent here. The same remarks regarding the avoidance of cyan, magenta and yellow filters together applies to Printon printing just as to negative-positive work. In order to avoid three filter combinations, calculations of corrections can be made in terms of filters which are to be removed from the pack rather than those which are to be added. For example, a magenta cast can be removed by adding green or removing magenta; if the filter pack contains magenta filters the latter is obviously the better alternative (see Over-filtration).

To assist in determining the value of the Ansco filters, a table of equivalents can be drawn up showing how each filter is related to the other in its group, for example, one yellow 25 is equal to two 24's or four 23's.

The following table shows the filter adjustments which can be made to correct for colour casts in the test strip.

Cast	*Add*	*Remove*
Yellow	Magenta and cyan	Yellow
Magenta	Yellow and cyan	Magenta
Cyan	Yellow and magenta	Cyan
Blue	Yellow	Magenta and cyan
Green	Magenta	Yellow and cyan
Red	Green	Yellow and magenta

If the test strip was made with magenta filter 34 plus cyan 44 and 45 it should be written:

M33	C43
33	43
	43
	43
	43
	43

If the print seems too blue but appears correct through a yellow 24, this filter should be added to the pack to give:

Y23	M33	C43
23	33	43
		43
		43
		43
		43

This can be simplified by removing the first two from each group of filters leaving only the four cyan 43's which are equivalent to one 45.

PRINTON PROCESSING
using Anscolor kits

STEP	NOTES	TEMP.	TIME in min.
1 First development	Agitate first half min. continuously, then every 15 sec.	68°F	14
2 Stop bath	ditto		2
3 Harden	ditto		4
4 Wash	In running water	50–75°F	5
5 Re-exposure	3 ft. from No. 1 photoflood		1 min. each side
6 Colour developer	Agitate first half min. then every 15 sec.		15
7 Stop bath	ditto		1
8 Harden	ditto		3
9 Wash	In running water	50–75°F	5
10 Bleach	Agitate first half min. then every 15 sec.		5
11 Wash	In running water	50–75°F	5
12 Fix	Agitate first half min. then every 15 sec.		5
13 Wash	In running water	50–75°F	10
14 Final rinse			1

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

PROJECTION

Colour transparencies are intended to be viewed by diffused light on an illuminated ground glass sheet in a slide viewer, or more generally by projection on a table viewer or a wall screen. In deciding on the necessary equipment the following should be remembered.

EXAMINATION OF EQUIPMENT

The general classification of projectors — by the wattage of the lamp — is inadequate. The total light output through the optical system should be the criterion. The total optical system includes the lamp, a reflecting mirror, a condenser and the image-forming objective. It is desirable to know the number of lux or foot candles received by the screen; if such a value is given it is not usually specified at what distance the reading is taken and therefore the figure is valueless. When a white screen is used, black-and-white transparencies require an illumination of about 100 to 200 lux; approximately twice this value is advisable for colour work.

Projector lamp Projector lamps are generally of a special type and are slightly over-run. They have a filament constructed as far as possible in one plane and occupying a small rectangular area. Best results are achieved with low voltage lamps but if the power is high this involves a rather heavy transformer. It is better to use a low voltage lamp and heavy transformer for a permanent installation and a mains voltage lamp for portable equipment.

Power The choice of power for a projector depends on its use. For domestic use a lamp of 100 to 200 watt together with a good optical system should be adequate but for use in halls up to 750 watt will be needed.

Ventilation When a lamp of greater power than 250 watt is used, forced ventilation of the lamp house is usually necessary as the lamp is invariably mounted in a restricted space. A small blower fitted under the lamphouse is cheap and simple to install and does not materially increase the weight.

Projector construction Projectors may be made of either metal or plastic; the metal ones whether of pressed sheet metal or die castings are stronger and have better heat conductivity but the latter are cheaper, lighter and require no expensive finishing process.

Installation During use two faults can occur:

1. Misting-up of the optical system: if the atmosphere is damp and the projector has not been pre-heated, condensation will occur on all glass surfaces and sharp images will be unobtainable. The projector must be switched off and all glass surfaces cleaned with a soft cloth. Wherever possible it is best to switch the projector on for a few minutes before use.
2. Low voltage or lamp darkening: the effect of both is the same, namely a darkening and yellowing of the screen image. The first fault can be overcome by using a constant voltage transformer or other type of voltage stabilizer and the second by replacing lamps as soon as any discoloration is seen.

The suggestion of using a blue filter over the lens has been made but this is not a good plan; colour distortion may take place and there is a considerable light loss. Lamp replacement is the only solution.

The screen The colour and surface of the screen can have a considerable effect on the quality of the projected image. The different types of screen all have their advantages and disadvantages.

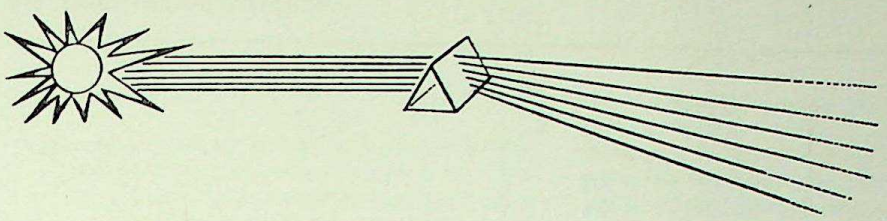
Metallized screens These give a sharp contrasty picture and there may also be a colour change.

Beaded screens give bright images if the audience is in a narrow arc close to the projection axis; this is not always possible.

White matt screen This is the best type for colour projection as there are no complications attending its use.

Viewing Obviously the screen image will not correspond exactly with the natural scene; there will be some discrepancies but these will not be too serious. In particular the projection image will appear like a scene viewed through a window and will be bright against a dark background. Under these conditions the colours will seem brighter than they were in nature surrounded by other elements of the same brightness. Another factor is that spectators do not all have the same vision characteristics. In particular older people exhibit a slight yellowing of the cornea and appear to see everything as if through a pale yellow filter. This becomes apparent from the age of 30 and is sufficiently important for the CIE to recommend that people above this age should not be employed in colorimetry.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



R

RECIPROCITY (Law failure)

Reciprocity law The reciprocity law states that to produce a constant density the product of intensity of light and time of exposure must be constant. If I is the intensity and t is the time, $I \times t = k$. This law is followed reasonably well in black-and-white photography and enables a correlation between shutter speed and aperture to be established over a relatively narrow range. Cameras having an 'exposure value' system make use of this relationship. When the product of intensity and time does not give a constant density reciprocity law failure occurs.

Historical The failure of the reciprocity law was noted in the earliest days of photography and it is particularly obvious in colour work. The first group of people to encounter difficulty with the failure of emulsions to respond to variations in time keeping the product $I \times t$ constant were astronomers who had to give very long exposures when photographing bodies of low luminosity.

Schwartzchild modified the reciprocity law to $(It)\rho = k$ where ρ is a coefficient less than unity and varying with the emulsion. It is in the region of 0·8. As ρ is less than unity it is obvious that for long exposures the photographic effect is far less than would be expected from the more straightforward Bunsen-Roscoe law. ρ is known as the Schwartzchild coefficient.

Schwartzchild's modification does not, however, answer the question of reciprocity failure completely, as photographic efficiency falls off not only with very long exposures but also with very short ones, i.e. where I is large t is small.

Graphical representation of this phenomenon The failure of the reciprocity law can be represented graphically as follows: log It necessary to produce a given photographic effect is recorded on the ordinate as density, whilst log intensity is recorded on the abcissa. If there were no reciprocity failure a straight line would be produced corresponding to each density D1, D2, D3 as shown in Fig. 1. With most emulsions, however, curves such as those in Fig. 2 would be obtained. From these curves it can be seen that at either short or long exposure times the photographic effect will be much less than if there were no reciprocity failure. In other words if two exposures are made, one at a normal time such as 1/10 sec. and one at a very brief time such as 1/10,000 sec. with a corresponding adjustment in intensity, the density produced by the exposure of 1/10,000 sec. will be less than that produced at 1/10 sec. This means that at 1/10,000 sec. the emulsion is less sensitive that it is at 1/10 sec.

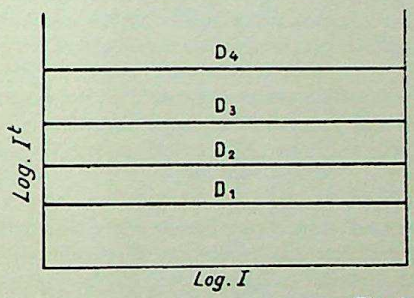


Fig. 1.

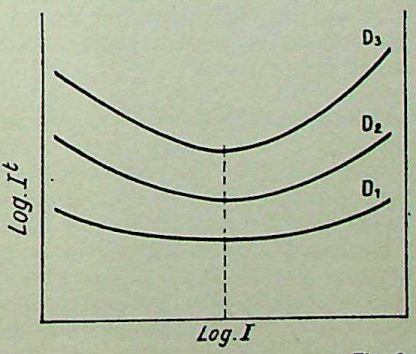


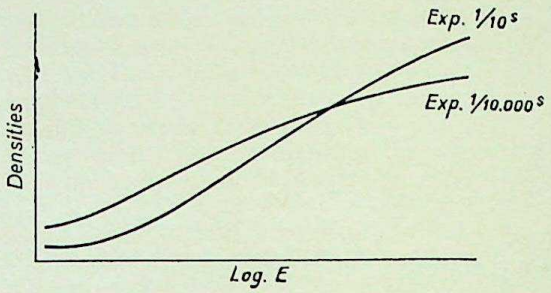
Fig. 2.

Practical examples In practice the most efficient exposure time is usually in the region of 1/10 to 1/50 sec. and if exposures are lengthened to several seconds or shortened to below 1/1,000 sec., signs of reciprocity failure will become apparent.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Examples With high voltage electronic flash, exposure times are very short and most negative materials suffer an apparent loss of sensitivity and contrast. For long exposures the following recommendations made for Ektachrome film Type B (Process E-3) will serve to illustrate the loss in sensitivity which occurs:

Uncorrected exposure time	*Exposure time adjusted for reciprocity failure*	*Effective ASA rating*
1 sec.	1 sec.	50
10 sec.	16 sec.	32
60 sec.	147 sec.	20
2 min.	6 min.	16
4 min.	16 min.	12·5



REFLECTION PRINTS

The production of positive prints on opaque bases produces many problems in addition to those usually encountered in the production of colour transparencies. The factors of colour rendering, sharpness, grain, etc, will not be reconsidered here. The importance of colour rendering is the same for paper prints as for transparencies; sharpness and graininess are less critical with paper prints for they are rarely examined with a magnifier. The main problem with paper prints is the base itself and the method of reflected light viewing.

Influence of the base material Generally colour print materials such as black-and-white ones use a paper base but some such as Ansco Printon and Kodachrome print film have a white pigmented cellulose ester film base. The bases are made as white as possible by incorporating barium sulphate (baryta) in the gelatin substratum of papers or titanium oxide as a pigment in the cellulose ester film.

Physical structure of the base Baryta paper base covered by various emulsion layers is not a homogeneous medium. This non-homogeneity will appear photographically in areas of uniform density — the sky for example — as a mottled effect. This mottled effect can appear in the yellow, magenta or cyan layer or in all three; this will depend on the layer's situation relative to the base. Usually the cyan layer is in contact with the base and the mottled effect will be particularly unpleasant when reproducing a blue sky. This is not surprising bearing in mind the importance in the final print of the cyan layer which has a high visual contrast as opposed to the low visual contrast of the yellow layer. Consequently if the paper is made so that the yellow layer is in contact with the base a yellow mottled effect will be almost invisible. Other defects such as irregular coatings or imperfect washing may also result in mottle although they are not necessarily connected with the prime cause of mottle. Reversal materials are more prone to mottle than materials printed from a negative. For example, with Kodak Type E paper, mottle could only be overcome by using the coating sequence described above. Up till that time reversal materials for making opaque base prints, e.g. Ansco Printon and Kodachrome print material had to be made on cellulose base which could be given a perfectly smooth surface.

Chemical composition The chemical composition of the paper base can influence the characteristics of the unexposed emulsion and of the processed paper print; in particular the binding agents may contain free formalin which may react with the couplers present in the photographic layers. All other practical characteristics of colour papers are influenced by the reflection method of viewing.

Examination by reflection

1. *Quality of the whites* — '*Anti-stain*', '*Optical bleaches*'. Photographic reproductions on opaque bases have the disadvantage that their tone range is diminished because the dense areas reflect light and the light areas absorb light. In the most favourable cases the density range is 1·8 giving a highlight to shadow range of 50:1. With transparencies on the other hand there is in theory no limit to the range and 1 to 500 can be reached in practice.

Reversal materials have a minimum density of about 0·25 and positive materials may be as low as 0·1. With paper prints the minimum density is kept as low as possible owing to the limitation of the maximum density and to this end manufacturers use the whitest possible paper base together with the clearest possible gelatin and emulsions of low fog and stain value.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

The maintenance of low fog and stain is made more difficult by the following factors:

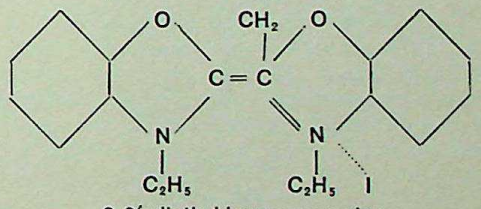
1. A silver fog level of 0·03 to 0·05 when measured by transmission is doubled if the same layer is applied to a reflecting base as the light must travel twice through the emulsion layer and hence be subjected to absorption in both directions. In addition the colour development process results in at least a two-fold intensification.
2. Secondly, stain may be produced during processing which is the result of spontaneous coupling and dye formation in the emulsion layer without reference to any silver image production. This can be reduced by the use of certain techniques. The presence of a reducing agent in the colour developer, or in the emulsion itself, frequently brings about a reduction in stain level as the reducing agent competes with the coupler for the oxidized developing agent. These anti-stain reducing agents are particularly effective in the improvement of stain caused by developer aerial oxidation.

Among the many compounds which have been patented are polyhydroxy reducing agents such as *lauryl hydroquinone* which has a long carbon chain in its molecule which prevents it from diffusing when incorporated in an emulsion, or ascorbic acid, which is more suitable for use in developers as it contains water solubilizing groups. Using such methods the densities of the whites can be reduced to about 0·1. Further reduction in white density was made possible using a method developed by the textile industry. It is now common practice to treat white textiles with a fluorescent substance which emits bluish-white light when irradiated by ultra-violet. These fluorescent compounds may be incorporated in the paper base, in the emulsion, or in a special layer, and prints treated this way will, when viewed by light containing a proportion of ultra-violet (e.g. daylight), be much brighter in appearance due to the reduction of their minimum density. It should be noted that the effectiveness of these compounds diminishes when prints are viewed using incandescent lighting owing to the lower proportion of ultra-violet.

Although the principles involved are the same, the optimum results in photographic work are not necessarily achieved with the best textile brighteners and most sensitive material manufacturers have taken out patents on suitable compounds. Probably the most important compounds in this sphere are the derivatives of diaminostilbens.

Under optimum conditions it is possible to reduce the density of the whites to about 0·06.

2. *Protection of the colour print and influence of ultra-violet radiation.* Reflection colour prints, particularly those on paper base, are subject to a wide variety of viewing conditions. They may be exposed for long periods to tungsten light, fluorescent light, or even to daylight. Daylight in particular is liable to damage colour prints as it contains a high proportion of ultra-violet radiation. The dyes used in colour photographs, like almost all other classes of dyestuff, are particularly susceptible to damage by ultra-violet. It is a basic problem in dye chemistry to find dyestuffs of high light-resistance; those used in colour photography are so poor in this respect that they have virtually no other commercial application. Photographic colour images can also be subject to fading caused by circumstances other than light. Heat and humidity are the main offenders and can result in reaction between dyes and residual coupler among other things. So far no system using coupler-containing emulsions enables the unused coupler to be eliminated after processing. Where couplers are not incorporated in the emulsion layer, for example in the case of Kodachrome, no interaction between dye and residual coupler takes place. Finally the residual couplers themselves can be photolytically decomposed usually producing a darker coloured substance which stains the whites. In the case of paper prints the problems are divided into two categories: light fading and fading in the absence of light. To improve light stability most manufacturers have obtained patents on the use of ultra-violet absorbing substances which bring about a considerable improvement (oxacyanines, benzocyanines, thiazolocyanines). If these compounds are made non-



2-2′-diethyl benzoxacyanine

diffusing by the incorporation of a long carbon chain in their molecule, they can be incorporated in a gelatine supercoat over the emulsion layers. Alternatively, soluble and diffusible absorbers may be introduced into the emulsion during processing, for example in the developer or in a stabilizing solution. Any instability due to the reactivity of residual couplers can be ameliorated by combining the coupler with a compound which blocks its reactive position. The reactive methylene groups of the magenta and yellow couplers are particularly susceptible to this form of stabilizing by the use of an aliphatic aldehyde such as formaldehyde (formalin).

$$\begin{matrix} R' \\ R \end{matrix}\!\!>\!CH_2 + OCH{-}CH_3 \rightarrow \begin{matrix} R \\ R' \end{matrix}\!\!>\!C{=}CH{-}CH_3$$

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

REVERSAL PROCESSES

In processes of this type, the emulsion of the camera film is used to form the final positive image by a suitable processing sequence. The usual structure of these films is shown on page 35, (and further information is given under Agfacolor, Anscochrome, Ektachrome, Ferraniacolor, Kodachrome, etc).

The basic requirements of a reversal colour film are:

1. Three emulsion layers respectively sensitive to blue, green and red.
2. During processing, three positive images (with respect to the original) in yellow, magenta and cyan dye are formed in the layers whose sensitivity is blue, green and red respectively (page 35).

The reversal process implies the production of the final positive image by development of the original film exposed in the camera, and differs from the autopositive black-and-white process where the positive image is produced in a special emulsion by a single development step. The limitations of the latter process (high contrast and low sensitivity) at present limit its use to special applications such as document copying.

With reversal films the processing starts with a black-and-white development step of the normal type which produces a negative image in the emulsion layer whose density corresponds to the formula

$$D = \log \left(\frac{E}{I}\right)^{\gamma}$$

It can be seen that the residual silver halide left in the layer at this stage constitutes a positive image. In fact if D_m is the maximum density which can be produced in the layer by developing all the silver halide, the difference D between this density and the already given negative density is

$$D_m - D = D_m - \log \left(\frac{E}{I}\right)^{\gamma}$$

D_m can be represented by the logarithm of a constant k giving

$$d = \log k - \log \left(\frac{E}{I}\right)^{\gamma} = \log k \left(\frac{I}{E}\right)^{\gamma}$$

This density is equal to the logarithm of the reciprocal of the transparency (opacity of the image) thus obtained:

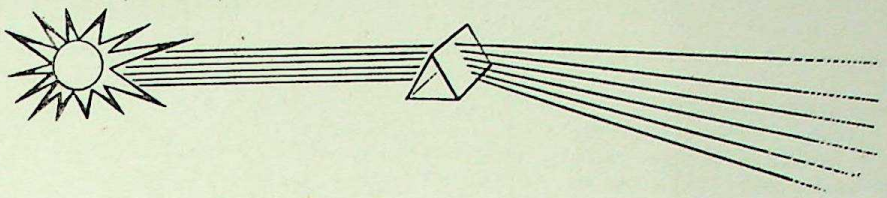
$$\text{Log} \frac{I}{t} = \log k \left(\frac{I}{E}\right)^{\gamma}$$

Finally, the transparency of the final image varies in the same direction as the exposure of the layer; it is therefore also a positive in the sensitometric sense of the word. This positive image has density or transparency in exact correspondence to the exposure if the gamma is unity.

The processing proceeds as follows: after the first development the intermediate negative image is removed by bleaching — that is by the action of an oxidizing agent which alone, or with another reagent, forms a soluble silver salt — for example: potassium dichromate and sulphuric acid. The still sensitive layer is now re-exposed uniformly to make all the residual halide developable, and a second development stage converts the residual silver halide image into a silver image having the properties already described. In practice the removal of the negative image in the oxidizing bath also changes the residual halide appreciably, and it becomes almost insensitive. The sensitivity is restored by an intermediate treatment in sulphite or bisulphite solution which also eliminates the excess oxidizing agent from the bleach bath.

For the same reasons as those described in the section on the negative-positive process, the gamma of a reversal film is rarely unity. The normal value for the gammas of sub-standard cine films is about 1·5. This means that reversal films have lower exposure latitude than negative films; in practice the maximum density which can be reached in a sensitive layer is about 3. As the density and gamma are both fixed the exposure scale is reduced to about 2 to 2·4 log E for the majority of reversal films, and is thus about half that for negative films. For this reason exposures must be determined with reasonable accuracy. These properties of reversal materials do not, however, appear to have had any great effect on their popularity on the amateur market where they are found for both black-and-white and colour work.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



S

SENSITOMETRY

Density The photographic effect of light is measured by the silver image produced after development. The developed image can then be measured to determine its capacity to absorb light. The most straightforward way of doing this is to make the measurement by transmitted light to give the transmission or opacity of the image.

Transmission is defined by the ratio $\frac{It}{Io}$

where It is the transmitted light and Io the incident light. Opacity is the reciprocal $\frac{Io}{It.}$

In most cases a more convenient unit is the logarithm of the opacity, known as the optical density or more simply the density of a silver deposit. It should be noted that transmission can vary from 1 to zero, opacity from1 to ∞ and the density from zero to ∞.

The notion of density was introduced by the originators of sensitometry, Hurter and Driffield, who found the logarithmic scale convenient to use in its relation to the exposure and amount of silver produced per unit area. If a photographic image contains n grains of uniform size per unit of volume and is separated into n elementary slices each of single grain thickness, a total effect will be obtained taking into account n superimposed layers each one of which absorbs a fraction b of the incident light. The transmitted light is equal to $(1-b)$ for each layer and $(1-b)^n$ for n layers. It can be shown that when b is low $(1-b)^n$ can be replaced by e^{-nb}; the opacity is then e^{nb}. Consequently when the grain size is uniform the density corresponds to the number of grains per unit volume.

Characteristic curve With light of constant quality the density of a silver deposit will be increased with increasing exposure time up to a certain maximum. Conversely if the exposure duration is kept constant the density will increase with increasing brightness up to a certain point. The relationship between density and exposure is shown in Fig. 1. This curve is obtained by plotting the density D against the logarithm of the exposure, that is, the product of the intensity of the light and the time which it is allowed to affect the film.

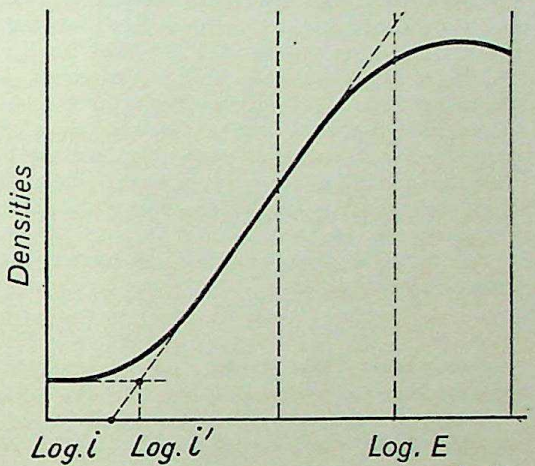


Fig. 1.

The characteristic curve can be arbitrarily split into four regions:

1. The toe.
2. The straight line.
3. The shoulder.
4. The solarization region.

The toe is often referred to as the region of under-exposure although the upper part of the toe can be extremely useful photographically. In the straight line region the density increases proportionately to the logarithm of the exposure. Some emulsions possess a very long straight line portion whereas with other emulsions the straight line is short and may even be merely a point of inflexion joining the toe and shoulder.

In the shoulder region increasing exposure produces steadily decreasing addition in density. The curve tends eventually to become parallel to the abcissa. Further along the log E axis is the region of solarization where an increase in exposure results in a decrease in density.

The density obtained under standard condi-

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

tions does not depend on the unconditional product of I and t. If I is great and t very short the resulting density will usually differ appreciably from that obtained when both I and t are of average magnitude even though the It product is the same in both cases. This phenomenon is called reciprocity failure (q.v.).

Gamma In the straight line part of the characteristic curve the increase in density is proportional to the increase in log E. We therefore have

$$D = \gamma (\log E - \log i)$$

In this equation log i is the point where the projected straight line intersects the abcissa. Gamma or γ is the ratio between increases in density and log E. It represents the slope of the straight line.

The value of log i has been considered as a criterion of photographic sensitivity, but if there is an appreciable fog level a correction must be applied and a reading is taken from the log E axis corresponding to a position on the projected straight line at the fog density. This is the point shown by log i in Fig. 1.

The actual figures of sensitivity are given by the reciprocal of i, that is

$$\frac{1}{i} \text{ or } \frac{1}{i'},$$

or a multiple of these values. It follows that the greater the sensitivity, the lower the value of i. There are other more modern methods of determining the sensitivity of an emulsion all of which are based upon the characteristic curve.

The characteristic curve is influenced by the emulsion itself and the way it is developed and modern emulsions exhibit a wide range of curve types.

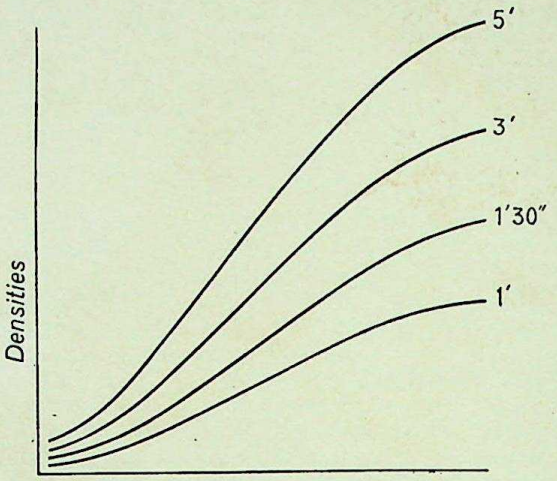


Fig. 2.

The chemical constitution of the developer, the time, temperature and method of development, are very important to the shape and position of the curve.

Fig. 2 shows various characteristic curves, each one for a different development time, all other factors being constant. It will be noted that γ increases with development time and this is the reason why gamma is often used as a measure of development.

SENSITOMETRY OF COLOUR MATERIALS

General The sensitometry of integral tripack colour materials does not differ greatly from that of black-and-white products except that three curves are used to represent the three layers of the material. The general system of determining the characteristics of a colour film is by exposure, processing and measurement in the usual way. A general object is to test new batches of film on paper by comparison with a known standard material which is kept under ideal storage conditions to minimize age changes.

As in black-and-white sensitometric work, the exposure of colour sensitometric tests should be carried out under conditions which are reasonably close to the conditions encountered during the normal use of the material. Light sources should be accurately calibrated by a photometric laboratory.

Sensitometers which are designed for black-and-white work are not necessarily suitable for colour as in most cases they have insufficient light output which is a disadvantage as colour films are almost invariably slower than black-and-white ones. Finally it is advisable to use a sensitometer having a fixed exposure time and variable intensity to avoid any difficulties which may be caused through the three layers of the film differing in their reciprocity failure.

The sample of film or paper should be exposed to a recommended light source (tungsten light of 3,200°K for example) through a step wedge with an increment of density 0·15 for example and giving steps of about 1 cm. square. The step wedge should cover a range beyond the useful exposure scale of the emulsion in both directions.

Exposures through colour filters may be given in addition to the white light exposures to determine the relative sensitivities of each layer. It is usually impossible completely to isolate one or two layers by means of exposure through filters in this way. Usually the density of individual layers has to be calculated from the total density measured by the white light exposure.

Development This may be carried out on a motion picture type of processing machine where

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

several tests are made and an average reading is taken or the tests may be processed in a piece of special equipment in which all the manufacturers' recommendations regarding time, temperature, agitation, etc, should be controlled as closely as possible. Attention should also be paid to solution control and to drying conditions.

DENSITOMETRY

(a) Integral and analytical densities Each step of the sample is measured through three filters whose transmission maxima should coincide with the absorption maxima of the three dyestuffs in use although some adjustment may be necessary in cases where the dyestuffs have secondary peaks in order to avoid measuring this secondary peak as far as possible (Fig. 1.) These three densities are plotted on graph paper so that finally these curves are obtained corresponding to the integral densities measured with blue, green and red light (Fig. 2).

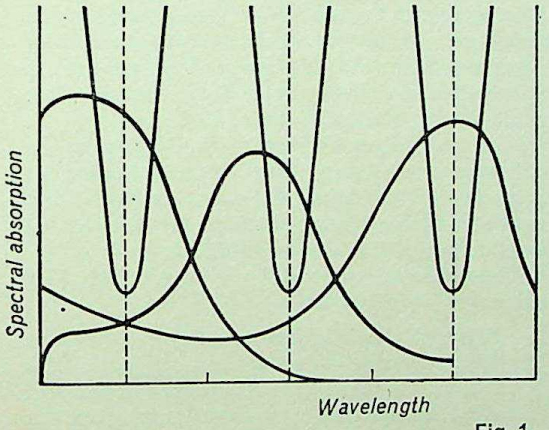


Fig. 1.

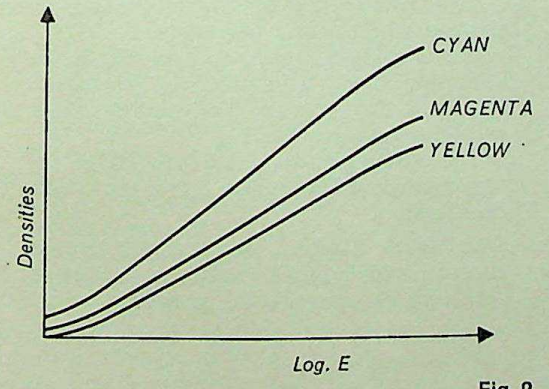


Fig. 2.

These integral densities do not correspond exactly with isolated elementary layers owing to the unwanted absorption of the dyestuffs (see Fig. 1).

Let us suppose that the subtractive system has absorptions for each of the three dyestuffs as in the following chart:

	Examining light		
Dyestuff	*Blue*	*Green*	*Red*
Cyan	b	a	1
Magenta	c	1	0
Yellow	1	0	0

The integral densities that will be termed D_1, D_2, D_3, having been measured in red, green and blue light, are the combinations of analytical densities that would have been obtained if the elementary layers could be measured and give the following relation:

$$D_1 = D'_1$$
$$D_2 = aD'_1 + D'_2$$
$$D_3 = bD'_1 + cD'_2 + D'_3$$

This shows that the analytical densities can be calculated from the integral densities once the simple linear equation relating the two has been established. The use of integral or analytical densities in colour sensitometry depends on the purpose of the investigation. In manufacturing processes analytical densities are of more value as they indicate the behaviour of the individual layers of a tripack. The simpler integral densities are, however, quite adequate for controlling processing in the laboratory as they indicate departure from standard conditions with sufficient accuracy. When difficulties arise it may be useful to calculate the analytical densities to locate the source of the trouble more precisely.

(b) Calculation of photographic parameters Instead of using the analytical or integral density curves in themselves, it is better for routine control of manufacture or processing to derive certain parameters which when plotted on a chart give a quick reference to the state of the process.

These parameters are characterized according to their use.

1. The published photographic characteristics available to the user. These are generally in the form of a sensitivity index. In the case of professional material curves may be published showing the contrast obtained with different developing times, particularly in the case of fine films.
2. Control characteristics of a product to see whether or not it matches the standard. According to the products type, the sensitivity, contrast and toe contrast in the case of positive emulsions are calculated.
3. The qualities which govern the consistence of a photographic process (development of roll film, printing colour prints or developing

◀ MIDSUMMER NIGHT — photograph by H. W. Gelbing with a Retina Reflex camera and Kodacolor film.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

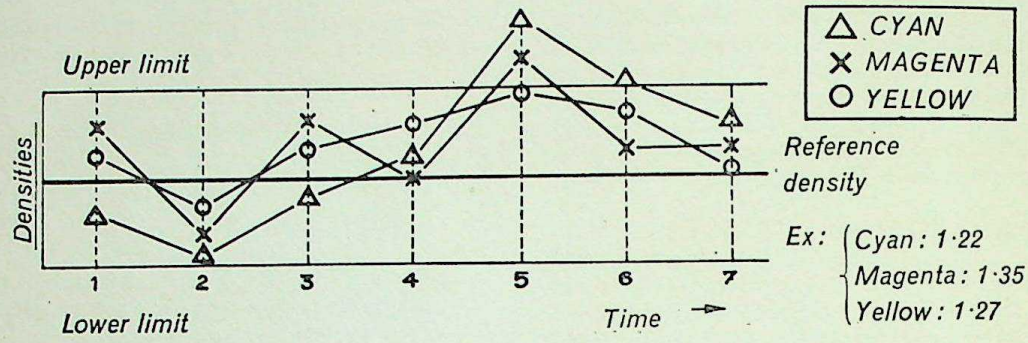


Fig. 3.

cine film). In the last case the fewest possible parameters are used enabling a very rapid check to be carried out on the process. To save time the characteristic curve is not always drawn; only 3 or 4 densities are measured to check the fog level, a mid density and the maximum density produced by the developer.

Each measured parameter should first have its tolerance values assessed. By joining up the plotted densities a graph will be obtained which immediately shows any tendency of the process to drift away from standard conditions.

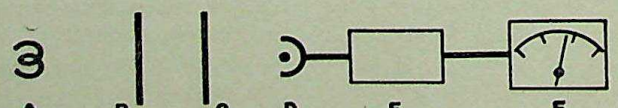
Fig. 3 shows a processing chart for Ektachrome film using one density only. Measurements 1, 2, 3 and 4 show that the process is in control but from the fourth measurement onwards the density increases. A chemical check on the first developer shows this solution to be nearing exhaustion and once this has been corrected the process is again in control as shown in the seventh measurement.

(c) **Apparatus** A few examples will now be given on densitometers which can be used for integral density readings. Analytical densitometers are available (Kodak, Gevaert, Agfa) but they are laboratory instruments rather than pieces of commercial equipment so will be not described.

All satisfactory colour densitometers which are used commercially are of the photo-electric type. Visual instruments which were used for black-and-white work have been abandoned for colour measurements because of their slowness and lack of precision.

A photo-electric densitometer has a basic structure of:

(A) Light source.
(B) Filter holder.
(C) Sample holder.
(D) Photo-electric cell.
(E) Amplifier.
(F) Indicator.



The use of very narrow cut filter packs which in some cases may have an effective density of almost 2 means that the photocell amplifier system must be extremely sensitive. The need for rapid measurements means that a direct reading instrument is required, shown diagrammatically above. The sample to be measured is placed in position and as soon as the switch is depressed the density is shown on the scale. This type of instrument has superseded the earlier types which were either zero reading or balanced types.

A considerable amount of work had to be carried out on the amplifier system and upon the method used to supply the lamp, as the direct reading system is particularly vulnerable to instability of either lamp or amplifier.

The principal problems have been resolved by using:

1. The high sensitivity of an electron multiplier tube operating on an alternating light beam of fixed frequency, the AC output of this cell being fed to a high gain amplifier tuned to the same frequency.

   Two methods can be used to produce an alternating output from the photocell.

   One is to use a rotating chopper disc in the light beam giving a frequency of 400 to 500 cps as in the Westrex Erpi and Eastman electronic densitometers.

   The cell output can also be modulated, for example by the Magnephot cell of the Welch densitometer.

2. The Ansco Macbeth densitometer uses a photocell coupled with an electron multiplier tube. In all cases stabilizing auxiliaries are

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

necessary to maintain the constancy of the instruments. The Kodak densitometer has sufficient sensitivity to enable colour densities up to four to be measured through the filters.

Maintenance of densitometers In normal laboratory use the densitometer must be checked daily; a transparent standard which can be kept free from changes or blemishes over a long period is therefore necessary. In practice the measured values must be extremely close to the standard values.

SEPARATION NEGATIVES

This is a photographic operation in which the subjects' colours are analysed by means of three plates exposed behind red, green and blue separation filters.

Separations made from the subject itself are called direct separations whereas those made via an intermediate colour negative or transparency are indirect separation. The term is not used when additive or subtractive colour films are used.

Two conditions are necessary for satisfactory separations.

1. A well-balanced fully panchromatic emulsion must be used.
2. Three filters must be chosen with the correct transmission curves. There is little to choose between the separation emulsions marketed by the various manufacturers in terms of spectral sensitivity or between the different sets of tri-colour filters. An important feature is the exposure factor which must be applied to each filter which is dependent upon the emulsion and upon the light used to make the exposure. These factors are given by the manufacturers for work both in daylight and artificial light.

Direct separations With stationary subjects the photographic technique is quite normal. The camera must be mounted on a rigid stand and all movements must be capable of being rigidly locked; a high quality lens should of course be used, free from chromatic aberration (see Camera and Lenses). Before using an emulsion or set of filters, tests should be made in daylight and artificial light to establish the correct filter factors. The best method is to photograph through each filter a grey scale made on ordinary bromide paper, basing each series of tests on the manufacturer's factor and the exposure which has been found necessary to give the first acceptable negative when no filter is used. The three negatives should be developed together for the same time as the negative made without a filter, and should be fixed, washed and dried under the same conditions. When viewed together on a viewing box, similar areas should have the same density or transparency. If there is an appreciable difference between one negative and the other two it should be remade, modifying the exposure to bring it into line. If the blue filter negative appears light and flat it may be necessary to keep the same exposure and to increase the development time. The contrast required in separation negatives will vary with the printing system. For imbibition processes, e.g. dye transfer, the gamma should be about 0·8 whereas for processes like Carbro a higher gamma — up to 1·2 — may be necessary.

When taking any photograph a grey scale should be included at the edge of the field in each negative to check for balance. Colour patches of either the mage colours in the case of photographic printing or inks in the case of photomechanical work can be usefully included alongside the grey scale.

The usual direct separation filters are the ordinary tri-colour set from the Wratten series Nos. 25(A) red; 58(B) green and 47(C5) blue.

Lighting contrast is as important when making colour separations as in any other branch of colour photography. The lighting ratio should not exceed 4:1. This can easily be checked with an exposure meter (see Exposure).

Indirect separation Indirect separations can be made by contact from a transparency but it is preferable to make enlarged separations. The enlarger must be completely light-tight and must have a lens with good colour correction; a filter draw is desirable (see Printing). Some means of varying the intensity of the light source should be available. As panchromatic emulsions are fast relative to materials normally used when enlarging, exposures should be made with the lens stopped down to $f/16$ or $f/22$ and an automatic timer used to control the exposure duration, which must always be held within close limits. The filters used for making separation negatives from transparencies should have a narrower transmission band than those used for direct separation work. The narrow cut tri-colour set is commonly used, i.e. Wratten No. 29(F) red, No. 61(N) green and No. 49(C4) blue. As the transparency will not normally contain a reference grey scale the negative carrier should have one of its rebates cut away in order to accommodate such a scale which is printed on a process type black-and-white emulsion. This scale should be reproduced on each negative to serve as a comparison between the three as in direct separation work.

As colour transparencies are generally hard, the separation negative, should be developed to a low gamma; 0·7 is high enough for most processes.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Before proceeding with the process of making separation negatives in order to produce paper prints from a transparency, the transparency should be critically examined to make sure that the results will be satisfactory. If the transparency is over-exposed the highlights will be washed out and if it is under-exposed or the contrast is too high, the shadow areas will lack detail. It must be remembered that a transparency when projected exhibits a much longer brightness scale than will be shown by a corresponding print viewed by reflection.

SHUTTER CALIBRATION

Accurate exposure standardization can be achieved experimentally by maintaining the shutter setting constant and varying only the aperture from shot to shot provided that prior tests have been made at this given setting. Between-lens shutters frequently show marked deviation between the theoretical and actual light transmission at a given setting. Instead of a separate exposure test for each speed setting it is better to check the actual performance of the shutter. This is relatively easy if a gramophone turntable driven by a synchronous motor is available; such motors have almost constant speed and their adjustment can be checked by means of stroboscopic discs.

Two small bulbs are fastened to the turntable and are connected in parallel to a suitable small battery; one bulb should be at the centre of the turntable and the other should be on the edge. The turntable should be on the floor and the camera located vertically above it about 3 ft. away, mounted for example on a tripod fitted with a tilting head.

The test exposures should be made in complete darkness and $f/8$ is a suitable aperture.

The exposure is made with the motor running and on each negative the central bulb will show as a point and the peripheral bulb as an arc whose length depends on the shutter speed and the speed of the turntable.

It is best to use the gramophone at 78 r.p.m. as the longer arcs thus obtained give greater accuracy.

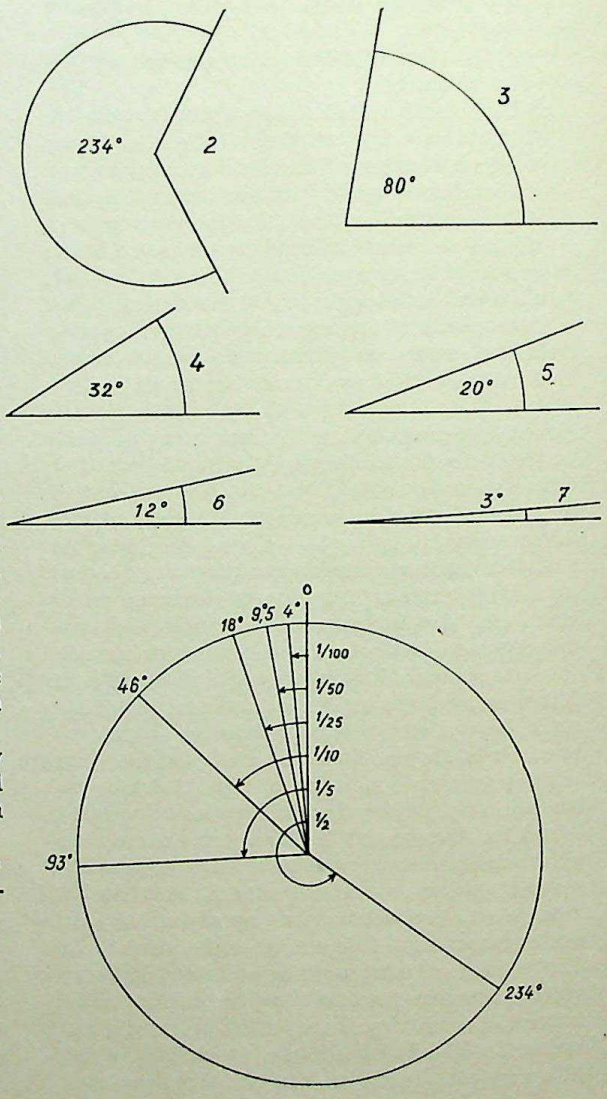
With each negative, lines are drawn from the centre to each end of the arc and the angle between the two lines is measured with a protractor.

From this angle the actual speed can easily be calculated and compared with the marked shutter speed which should of course have been carefully noted for each exposure.

At 78 r.p.m. the turntable will revolve $78/60 = 1{\cdot}3$ times or $1{\cdot}3 \times 360 = 468°$. Therefore the following times and angles will apply:

1/2 sec.	234°
1/5 sec.	93°
1/10 sec.	46°
1/25 sec.	18°
1/50 sec.	9°
1/100 sec.	4½°

Instead of making these calculations a circular diagram can be prepared which immediately gives the shutter speed without calculation. The chart is easily made with a compass and protractor and for simplification drawings should be four or five times the size of the negative.



CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

TYPICAL ERRORS

TEST	MEASURED ANGLE	MEASURED SPEED	MARKED SPEED	% ERROR
1	380/468	0·812	1 (1 sec.)	− 18·8
2	234/468	0·500	0·50 (½ sec.)	Nil
3	80/468	0·171	0·20 (⅕ sec.)	− 14·5
4	32/468	0·068	0·10 (1/10 sec.)	− 34
5	20/468	0·042	0·04 (1/25 sec.)	+ 10
6	12/468	0·027	0·02 (1/50 sec.)	+ 35
7	3/468	0·006	0·01 (1/100 sec.)	− 40

The negatives should be projected on to the diagram using an enlarger or slide projector. One end of the arc and the centre are made to coincide with the beginning of the circular diagram and a light line is drawn in from the centre to the other end of the arc. This will show the angle and hence the shutter speed. As the 1 sec. exposure is more than 360°, the measurement must be made on the double exposed arc of the negative and 360° added to this reading. In the example given earlier, the expected 1 sec. will correspond to a doubly exposed arc of 20° instead of 108°, giving a total of 380/468 sec. actual exposure. Adjustment of shutters is not possible but if the error is constant for each speed setting then a slight adjustment to the diaphragm can be made to compensate for such errors.

In practice the most useful speeds are 1/30 and 1/60 sec. and there should be no difficulty in remembering the compensation necessary at these speeds.

SPECTRAL SENSITIVITY

1. Introduction The natural sensitivity of silver halide emulsions is in the near ultra-violet and blue; this follows the absorption of blue light by the yellow crystals to produce a photo-chemical reaction.

For example, silver chloride emulsions, which are practically white, are only sensitive to violet and ultra-violet. Silver bromide, which is pale yellow, has an intrinsic sensitivity up to 500 mμ. Chlorobromide emulsions on the other hand have extended sensitivity up to 540 mμ.

All of these emulsions have some sensitivity to radiations of longer wavelength but this sensitivity is only in the order of a millionth of their blue sensitivity.

Colour photography in particular and all types of modern photography in general depend on the ability to make silver halides sensitive to all spectral regions. This colour sensitization depends on the use of sensitizing dyes (see Chart giving the historical steps of colour sensitizing).

2. Optical sensitization with dyes By including special dyes in the photographic emulsion during manufacture, the spectral sensitivity can be extended throughout the visible spectrum and even into the near infra-red as far as 1,300 mμ. It is difficult to extend the sensitivity much further because of the absorption by water vapour in the atmosphere and even in the emulsion itself.

The spectral sensitivity of an emulsion can be readily studied by exposure in a spectrograph whose slit is covered by a neutral wedge (see Sensitometry). The appearance of the image is shown in Fig. 1.

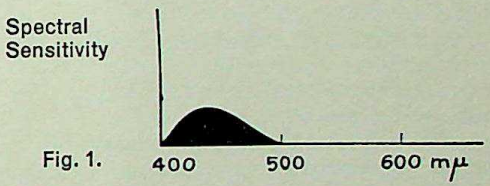


Fig. 1.

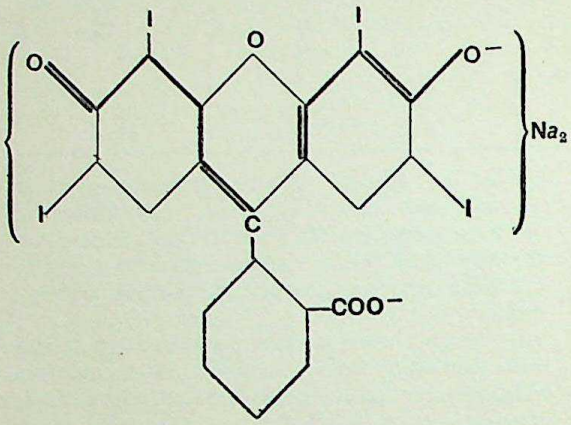
The greater the extent of spectral sensitivity the greater the horizontal spread of the black area. The relative sensitivity at any wavelength is shown by the height of the black area. In the case of an iodobromide emulsion, for example, it can be seen that the sensitivity maximum is at about 470 mμ. In practice when an emulsion is exposed to white light — or to any other radiation — it integrates all the photographic effects which would be produced at each individual wavelength.

3. Sensitizing dyes Since Vogel's discovery of the phenomenon of colour sensitization in 1873, most dyestuffs have been tested for their photographic effect. Out of these investigations it became obvious that certain classes of dyestuffs are particularly suitable for this work. The first class used was the cyanines, now superseded by the more efficient carbo cyanines and merocyanines.

All dyestuffs, and particularly the photographic sensitizers, contain as an essential feature a resonance chain called a chromophore linking two carbon atoms which are also attached to variable charge groups called auxochromes. The resonance chain consists of an odd number of carbon atoms linked by alternate single and double bonds.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

Example: $=C-C=C-C=C-$. The auxochromes are usually oxygen-containing groups such as OH or nitrogen-containing such as NH. Example: erythrosine derives from phthalein:



In this diagram the resonance chain is represented by the thick lines and the auxochromes are the two oxygen atoms at the terminations of the resonance chain.

4. Mechanism of optical sensitization The mechanism by which the luminous energy acts via the sensitizing dye to form the latent image is not clearly understood.

One essential feature of optical sensitization is that the sensitizing dye should be strongly absorbed on to the surface of the silver halide crystal. Most of the sensitizing dyes are weakly basic and this adsorption occurs quite readily, but non-ionic dyes can also be used as colour sensitizers.

If a solution of an ionic sensitizing dye is added to a suspension of a silver halide in water the dye will be immediately adsorbed on to the surface of the crystals. This can be seen quite clearly if the crystals are allowed to floculate, as there will be no dye in the supernatant liquor. This adsorption will continue up to a certain point which probably corresponds to the formation of a monomolecular layer of the dyestuff over the surface of the silver halide crystal.

The presence on the surface of the crystal of compounds such as antifoggants hinders optical sensitization.

Depending on the constitution of the dyestuff the colour when adsorbed on to the silver halide crystal may differ completely from the colour in solution in water or alcohol. What in fact governs the colour of the adsorbed dyestuff and the colour of the sensitized emulsion is the state in which the dye is adsorbed and the complex formed between the dye and the silver halide. Leermakers was able to show that the absorption curve of an emulsion corresponds exactly with its spectral sensitivity curve (see Fig. 2).

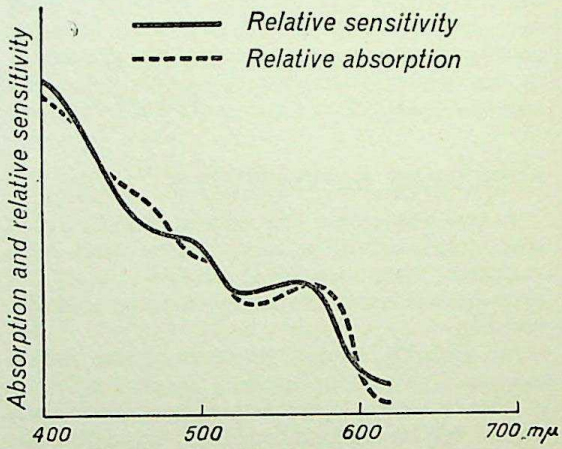


Fig. 2.

The spectral sensitivity increases with the amount of sensitizer up to a certain limit and then decreases. This is probably due to absorption by the excess dyestuff. The actual amounts of sensitizer used in practice are extremely small and correspond more or less to the amount of dye required to produce a monomolecular layer of dye over the surface of the silver halide crystals.

SPELAEOLOGY (Cave)

Despite the apparent lack of colour underground it is nevertheless of considerable interest to the colour photographer. In fact no other means are available to adequately present the clammy atmosphere with moisture glistening on the wall. Black-and-white photography cannot possibly give the realistic effects obtained with colour. Furthermore the variations in the colour of the walls (for example the caves at Lascaux and Cabrerets) are of great interest. These colours, ochre for yellow and red, manganese salts for violet-black and chalk and lime for white, were the only ones available to the prehistoric cave painters. If accurate documentation of cave paintings are required there if of course no alternative to using colour.

Colour photography in caves is no more difficult than black-and-white photography. There are two distinct types of photograph which can be taken; firstly the general tourist snapshot type taken on organized visits through caves and secondly the serious work of the investigator during an exploration.

1. Organized visits to caves The main requirements are that the camera should be loaded with artificial light film and a firm tripod should be available. In well illuminated caves it may be

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

possible to obtain adequate exposures in 1 to 5 min. at $f/5{\cdot}6$. The presence of water reflections adds interest to the photograph. If flash equipment is available the most interesting parts can be locally illuminated by flash during the main exposure. Before taking any photographs it is advisable to check on the Authority's attitude.

2. Spelaeologic explorations In this case it is better to load the camera with daylight film and use either blue flashbulbs or electronic flash. All equipment should be kept in watertight containers. Owing to the general dampness the lens should be cleaned before each exposure using lens tissue. With 10 ASA film close-ups present no problem. For photographs of more distant objects either more powerful lamps (for example PF100/97 or 350 to 400 joules electronic flash units) or faster colour film must be used. Colour films of 100 ASA and more are now available and greatly simplify this type of work.

STAINED GLASS WINDOW PHOTOGRAPHY

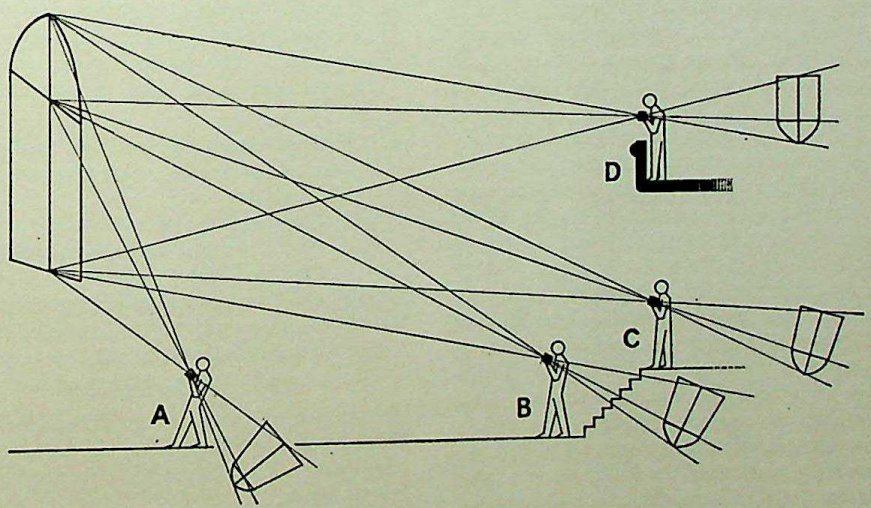
Stained glass windows are now rarely photographed other than in colour. There are no particular difficulties in this type of work for the photographer who is well prepared and equipped. On the other hand a casual attitude may lead to disappointment.

Organized photography of stained glass windows Whatever the type of building it is advisable to ascertain the conditions under which photographs of the window can be taken. The verger or vicar of a small church may be approached on the spot but in the case of larger buildings prior consent in writing may be necessary. A small fee may be requested or simply a donation to local funds.

When the particular window required is inaccessible, for example a window high in the nave, it may be possible to take photographs when scaffolding is erected for maintenance work or a suitable though distant viewpoint may be found when a long focus or telephoto lens can be used. Careful note should also be taken of the lighting of the various windows of interest so that the times when they are best lit can be estimated.

Any type of camera can be used but interchangeable lenses are highly desirable. In particular long focus or telephoto lenses enable windows to be photographed without the need to approach too closely and in many cases their use reduces distortion which would be present if a normal focus lens and close viewpoint were used.

The window should be illuminated by natural lighting. If sunlit, the best position is with the sun's rays striking the window obliquely from a high position but a slightly overcast sky is also



A. Low viewpoint and normal focus lens give serious distortion.
B. The use of a telephoto lens and a more distant viewpoint reduce the distortion in proportion to the increase in distance.
C. Raising the viewpoint reduces distortion still further.
D. A high viewpoint, together with a telephoto lens, removes all distortion.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

excellent. With either of these conditions at midday the results may tend to be too blue but excellent photographs of stained glass are obtainable in the morning or evening. Alternatively a pale yellow correction filter will give the same result.

Under the lighting conditions mentioned, the exposure time may vary between 1/50 sec. at $f/8$ for light windows to 1 sec. at $f/4$ for older, dense windows using 40 ASA film. Further stopping down serves no useful purpose as there is only one plane to consider and depth of field is not needed.

If the window is accessible the brightness can be measured with an exposure meter; when the window is not accessible then an object outside the building but lit in the same way as the window should be measured instead — for example the adjacent wall. The following factors must be taken into account: if the external reading indicates 1/100 at $f/4$, then an exposure time of 1/50 at $f/4$ will be suitable for a light-coloured window, being increased up to 1 sec. at $f/4$ for a very dark old window.

Normally the window will be reproduced as a coloured area against a black background but if details of the surrounding atchitecture are required then supplementary flash must be used. Electronic flash is the most convenient but blue flashbulbs can be used and the flashgun should be equipped with a long synchronizer lead to assist the placing of the lamp.

Tourist photography In general it is possible for the casual and unprepared visitor to take successful photographs of stained glass with a little prior knowledge. The advice already given should be of assistance and excessive haste generally results in disappointing photographs. To avoid movement, the camera should be held against a pillar or a chair. A general view of a window can give very good results but close-up details are often more impressive. Highly-placed, isolated windows should be avoided owing to the inevitable distortion.

STEREO PHOTOGRAPHY

Definition Stereo photography is an attempt to reproduce the effect of binocular vision giving a natural sense of depth and solidity. Although photographic techniques are used, stereo photography does not depend on interpretation of a two-dimensioned reproduction to give a sense of depth but is actually able to convey this relief to the viewer.

Procedure The perception of surroundings is through the senses which transmit their impressions to the brain. If the stimuli forming these impressions are produced artificially the brain will assume that the given object is present. It is well known that vision is the sense most easily deceived if an image can be formed on the retina of each eye similar to that which would be seen when viewing an object normally. The two eyes see the same objects from slightly different positions, being separated by a distance of 60 to 68 mm. (average 63 mm. for most people). The two images cannot therefore be exactly superimposed and the brain will, through a remarkable synthesis system, build a three-dimensional impression from these two slightly dissimilar images. This image is mentally projected forward so that it virtually coincides with the observed objects — so much so that one feels like stretching out a hand to seize them. This is due to the effect of binocular vision and the telemetric effect caused by the convergence of the two optical axes.

Relief impression in stereo photography. To give the same effect as that produced when a scene is actually observed, a photographic reproduction must have three attributes simultaneously.

1. The production of a pair of stereo images. This involves the taking of two photographs of the same object from positions separated by the normal eye spacing. The optical axes of the lenses must be perfectly parallel. The right image must be viewed by the right eye and the left image by the left eye exclusively.
2. The photographs must be viewed in normal perspective and magnification so that the images of the reproduction appear on the retina the same size as would the actual objects.
3. The photographic reproduction itself must be satisfying in the following respects:
   (*a*) No grain.
   (*b*) Good definition.
   (*c*) Good overall sharpness with adequate depth of field.
   (*d*) Good tone reproduction throughout the density range, in particular avoiding dense shadows which are acceptable in normal photographic work.

Influence of colour Although colour is not vital in stereo photography it does contribute to the effect of realism which is the main aim of stereo work.

(*a*) Natural colours are very varied; normally these are not noticed but in reality the visual monochromatic landscape is made up of small areas of different hue which the colour film reproduces. This applies equally to photographs of snow scenes as to any other subject;

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

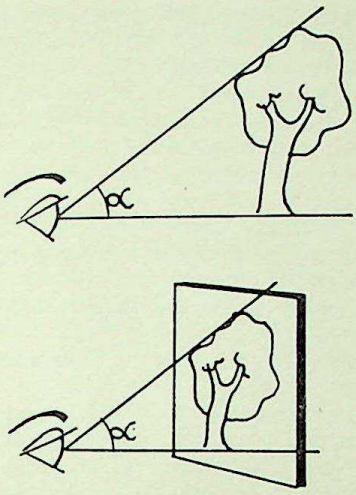


Fig. 1.

three-dimensional photography cannot reach the same degree of realism in black-and-white as in colour.

(*b*) Colour contributes a sense of shape in objects, irrespective of lighting. A photograph that would have seemed extremely flat in black-and-white will have far more depth in colour even with frontal lighting.

(*c*) With greater distances only colour film can create the sense of atmosphere given by the gradual colour change to blue with increasing distance.

(*d*) The recent revival of interest in stereo photography is largely due to the developments that have taken place in colour photography.

Stereo photography processes All stereo processes are based upon the concept of binocular vision.

Except for processes which involve some form of rebuilding of the object itself, all stereo processes are attempts to show two different photographs to each eye independently. The difference between the various methods is mainly in the way in which the images are presented to the observer.

The principal ones are:

1. Stereoscopy.
2. The use of lenticular embossed films.
3. Extra wide screen photography.
4. Positional stereo processes.

All of these processes are of scientific interest and practical processes have been based upon certain of them. Stereoscopy, however, is the only practical process for amateur work. For this reason the other methods will not be dealt with in this section on stereo colour processes.

Stereoscopic colour photography From the Greek *stereos* (solid, real) and *skopein* (to examine), this is the oldest and most successful method of giving a three-dimensional effect. It is based upon the simultaneous photographing of a subject from two positions corresponding to the two eyes viewing the same subject. Each of these views is then viewed exclusively by the appropriate eye.

TAKING THE PHOTOGRAPH

A. CONDITIONS NECESSARY FOR CORRECT PHOTOGRAPHS

1. The two camera lenses must be identical.

2. The optical axes must be parallel even in the case of close-ups.

3. The two positions are displaced horizontally, as are the two eyes. It is also disturbing if the sky-line is inclined or if the camera has been tilted so that verticals converge.

4. A large depth of field. It is vital in 3-D viewing that there should be no differential focusing between foreground and background. All parts of the field of view must be equally sharp. It is therefore necessary to stop down as far as possible consistent with using a sufficiently fast shutter speed. Colour films of 50 or even 100 ASA are therefore preferable as they give greater freedom in this respect. If sufficient depth of field cannot be obtained by stopping down it is better to focus at the hyperfocal distance and suffer some loss of sharpness in the foreground than to have foreground objects sharp at the expense of the more distant parts. This, of course, applies only if the background has any interest in it. For example, if an outdoor portrait is to be taken with the sky or distant landscape as a general background, the model should be in sharp focus.

5. Contrast limitation. The necessity for reducing the brightness range of the subject to avoid either clogged shadows when highlights are correctly exposed or alternatively burnt-out highlights when shadows are correctly exposed, has already been mentioned. The limited contrast range which a colour film can record should always be remembered and, if necessary, exposures must be made using the highlights as a basis and clogged shadows should then be avoided by the use of supplementary lighting or reflectors.

6. Absence of grain. When viewed under normal conditions in a viewer or by projection the image should show no sign of grain since this can be very disturbing in the mental synthesis process.

B. CAMERAS

Stereo colour photographs can be taken with any type of camera provided that two successive exposures are made by shifting the camera the necessary inter-ocular distance between the two

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

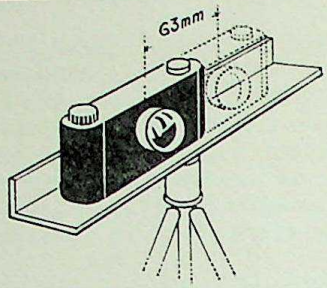


Fig. 2.

exposures (Fig. 2). Some well-known cameras are provided with commercial adapters for carrying out this movement — for example the Rollei stereo head. The limitation of this method is that there must be no movement of the subject between the successive exposures and only landscapes on a still day, or inanimate objects, can be photographed. Prismatic or mirror beam splitters are also available which clip over the ordinary lens and produce a side-by-side stereo pair in the normal picture space. Each image of the pair will be half the size of that normally given by the camera.

The resulting pictures can either be viewed without splitting using an optical system which is the reverse of the taking system or they can be cut in half and mounted in stereo slides to be used in a normal stereo-viewer.

When taking photographs it must be remembered that the field of view is only half that normally covered by the camera. The best method is to use a camera which has been specially constructed to take stereo photographs. The following conditions are necessary in good stereo equipment.

1. *Size.* Miniature cameras are better than their larger counterparts, as for a given aperture the short focus lenses which they use give the depth of field which is so desirable in colour stereo photographs. Cameras using 35 mm. film are particularly adaptable to stereo work although other stock sizes are used.

Cameras can be divided into two groups according to their image proportions.

(*a*) Cameras using the ASA standard of 24 mm. high by 22·5 mm. wide.

(*b*) Cameras of European origin using a horizontal format 30 × 24 mm.

As the eye tends to see a field which is wider than it is high, the European standard gives a more pleasing result. However, the economy of the American system is greater — a twenty-exposure 35 mm. cartridge gives fifteen pairs, whereas only twelve pairs are obtainable with the European standard. For the discriminating amateur there is little doubt as to which size is preferable.

2. *Lenses.* High quality lenses are essential for stereo photography and four-element lenses are to be preferred. The necessity for having adequate depth of field eliminates the necessity for large apertures; *f*/3·5 is more than enough.

3. *Shutter.* The two shutters must be closely matched otherwise the exposure of the two frames will not be identical. The most satisfactory type of shutter is a two-bladed non-adjustable type such as that on the Verascope 40. This shutter is also provided with contacts for electronic flash or expendable flashbulbs.

4. *Automatic adjustments.* The speed at which the film can be advanced, the shutter wound and the focus set, is often of great importance in securing a good shot. Most stereo cameras have a lever wind system which in one movement advances the film, cocks the shutter and changes the frame indicator. A coupled diaphragm/shutter speed adjustment together with an automatic light level indicator is also desirable.

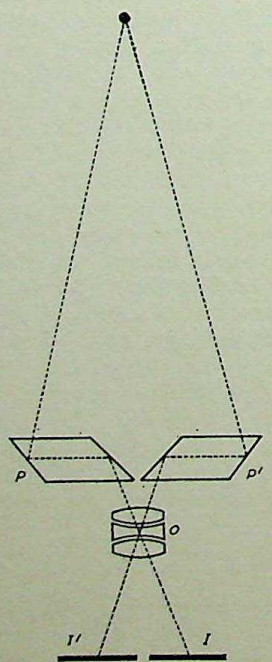


Fig. 3. Stereotar attachment for Contax.

C. COMPOSITION RULES FOR 3-D PHOTOGRAPHY. Colour stereoscopy has no particular difficulties and needs no specialized knowledge. The following basic rules will help in the creation of stereo photographs which really appear to have great depth.

The composition must be based upon the presence of different planes in the subject area and the balance of these planes must obviously be pleasing. A succession of different planes from about 10 ft. to infinity is desirable and lines or planes stretching from close up to the far distance are always of great assistance; for example walls, piers, footpaths, narrow streets, passages, and so forth.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

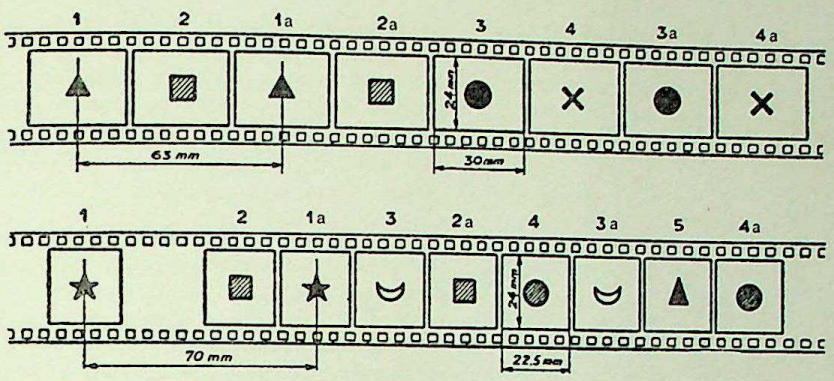


Fig. 4. Arrangement of stereo pairs.

EXAMINATION OF THE SLIDES

To obtain a 3-D impression the photograph should be examined at such a distance that the vision angle is the same as that occurring naturally. If the photograph is too far away the relief effect will be exaggerated and objects will suffer an apparent elongation towards the observer. To a large extent this distortion can be tolerated and this is in fact the case with stereo projection in a large hall where the effect is acceptable to the whole audience though theoretically correct for only one row of observers.

1. Slide mounting Generally the stereo pairs taken with the majority of cameras are viewed without prior magnification or reduction. Most amateurs will use reversal film stock which gives positive transparencies suitable for direct mounting and viewing. Alternatively negative film can be used from which contact prints are made and treated like transparencies. This latter course results in some loss of definition but enables many copies to be made if required.

Once the film strip is cut the following mounting procedure should be adopted:

(*a*) Place the left eye image to the left and the right eye image to the right.

(*b*) All frames must be reversed relative to their position on the film and placed so that the objects in the picture appear the right way round.

(*c*) The two images of a pair must be positioned on the same horizontal straight line so that neither is tilted relative to the other.

(*d*) Similar points of the two frames must be separated by a distance corresponding to the inter-ocular distance (generally 63 mm.). The mounting of the slides is relatively easy using cardboard mounts or hard rubber frames, the latter being particularly simple as alignment and adjustment are automatic. Furthermore the film is protected against dust, scratches and stains by cover glasses on each side.

2. Stereo-viewers The stereo-viewer assists the creation of depth illusion by

(*a*) presenting each image to the correct eye independently and

(*b*) magnifying each image so that it is at the correct viewing distance to produce the correct size impression on the retina.

The distance between the eye and the slide must therefore be equal to the focal length of the camera lens. For example, if the camera has 40 mm. lenses then the eyes should be 40 mm. from the slide. As this distance is much less than the normal close viewing distance of 150 mm. the eye is assisted by a converging lens of 40 mm. focus.

If the two transparencies are situated at the focus of the viewing lenses, no visual focusing will be necessary and the scene will appear as in reality. As the hyperfocal distance of the eye is about 10 ft., objects beyond this will normally be seen without any focusing reaction. The eyes when looking through the stereo viewer will therefore have exactly the same impression as would be obtained when looking at the actual objects photographed. The brain will complete the synthesis of the two images to give the illusion of reality.

The simplest stereo viewers consist of a flat box, one end of which is punctured by two holes, each fitted with a viewing lens (magnifier). At the other end of the box is a slot to accommodate the slide and behind the slide is a diffuser. More elaborate models will have a knurled knob for altering the focus of the magnifying lenses, a device for adjusting the inter-ocular distance and a self-contained light source, either mains or battery operated.

With practice and under suitable conditions, the stereo effect can be seen by straightforward examination by the naked eyes. The pair of prints is disposed horizontally and a sheet of opaque material is held perpendicularly to the prints to avoid overlapping images. The viewing distance will, however, be too great, resulting in too small an image and exaggerated perspective. To obtain

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

correct orthostereoscopy, some degree of enlargement is essential. As the normal viewing distance is about 30 cm. or eight times the focal length of the taking lenses, the photographs must be enlarged

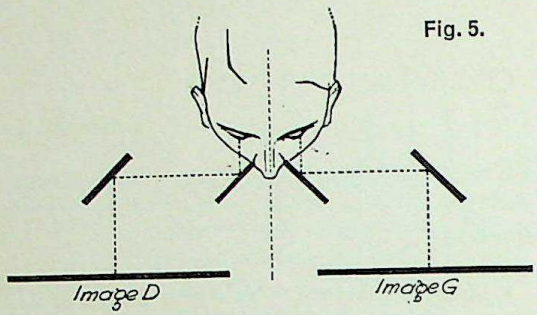


Fig. 5.

about eight times to give a proportional impression. Thus, from a 24 × 30 mm. frame a print of about 19 × 24 cm. should be made. As it will then be impossible to position two such prints so that corresponding points are 63 mm. apart a mirror or prismatic optical system must be used for viewing. An alternative method which uses colour but does not give a colour image is the anaglyph which, by means of coloured images and spectacles, presents each eye with a different picture in light and shade which the brain fuses into a stereo effect.

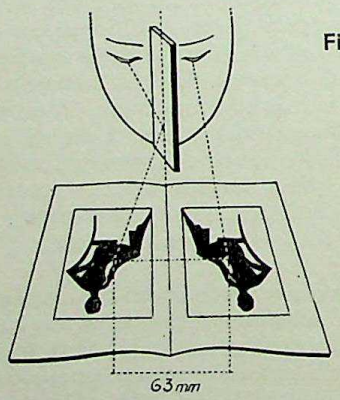


Fig. 6.

3. Slide projection Various methods have been suggested to overcome the difficulties of stereo projection. They include:

(*a*) The projection of two slides side by side together with examination using special selective spectacles.
(*b*) Successive projection of the two slides and examination by means of synchronized 'blinkers'.
(*c*) Anaglyph projection.
(*d*) The use of a fixed or moving net (the cyclostereoscopic screen).
(*e*) Lenticular screen methods.
(*f*) Use of polarized light.

Only the latter process is sufficiently straightforward and satisfactory for general amateur or commercial use. Unlike the anaglyph system it permits colour projection without alteration of the colour.

Principle of polarized light projection The two slides are projected together on to the same screen through a pair of side-by-side projectors each of which is fitted with a polarizing screen over the lens. The image to be viewed by the left eye has the polarizing screen inclined, for example, at an angle of 45° to the left; in other words the two polarizing screens are perpendicular to each other. The viewing spectacles are fitted with polarizing filters similarly inclined so that the left eye will see the left eye image and the right eye only the right eye image (Fig. 7).

As explained in the section on Polarization, a beam of polarized light will pass freely through a polarizing filter oriented in the same way as the filter which caused the light to be polarized but will be completely stopped by a filter whose orientation is at right angles to the direction of polarization.

The impression obtained by this system of stereo projection is basically the same as that obtained when stereo slides are examined through a viewer with the difference that whilst the viewer system can only be used by one person at a time the projected scene can be examined by several people simultaneously.

One essential feature is that the screen must not depolarize the light and although the beaded screen has otherwise many points in its favour, it cannot be used in this application. The most suitable non-depolarizing screens are:

(*a*) metallized screens
(*b*) multicellular screens having their surface covered by very small polished aluminium spherical mirrors.
(*c*) special beaded screens having the rear part of the bead silvered and the front face frosted.

Conditions necessary for good projection The screen should always be as large as possible bearing in mind the power of the projector; this tends to make the observation distance less critical. If only a few observers need be considered a 4 ft. screen can be used with an audience of two or three situated at or near the projector axis.

As the ideal viewing distance is about 1·5 screen widths from the screen, the first spectator will be about 6 ft. away. Contrary to the usual cinema seating, the viewers nearest the screen will have the best impression. Distances greater than five times the screen width should be avoided otherwise perspective distortion becomes excessive.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

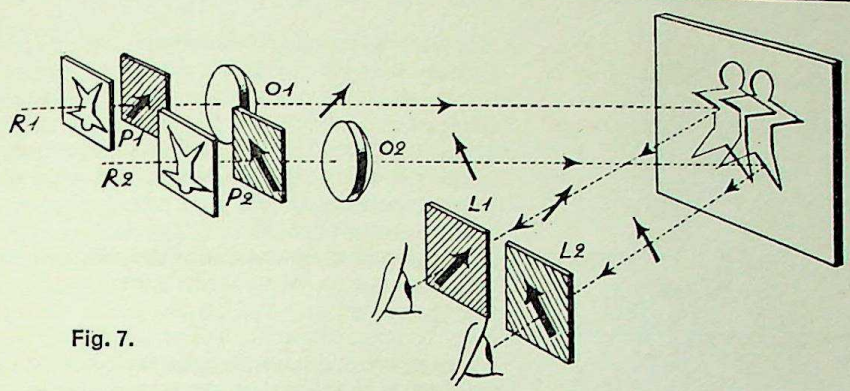


Fig. 7.

Projection with polarized light.
R1, R2 stereo pair.
P1, P2 projection polarizers.
O1, O2, lenses.
L1, L2, polarizers in front of observers' eyes.

For larger audiences high reflectance screens should be used with a minimum width of 5 ft.

Inclination of the head to the left or right should be avoided as this will tend to lose the stereo effect by permitting each eye to see the wrong image due to the polarization axes of the spectacles and projectors no longer corresponding. The polarizers on the spectacles should be kept clean and excessive handling avoided.

The two projected images will not coincide exactly, as they were not photographed from exactly the same position, so it is necessary to carry out any image coincidence adjustments on a distant object, for example a lamp-post, telegraph pole or tree silhouetted against the sky. No variation in height between the two images can be tolerated otherwise the audience will suffer some discomfort. This is one of the reasons why public cinema projection of polarized stereo films is reputed to be-tiring. It is therefore essential to be able to correct any discrepancy in this respect immediately when changing from one slide to the next.

Projectors A good stereo projector must have the highest powered lamp possible as the polarizers absorb three-quarters of the available light.

It will therefore need:

(*a*) heat-absorbing filters and a powerful blower to avoid over-heating of the slides
(*b*) rapid yet controlled lens adjustments for focusing and registration
(*c*) a firm stable slide holder giving almost automatic slide changing.

4. Stereo movies Stereo movies should not be confused with panoramic cine projection with or without stereophonic sound (Cinemascope, Cinerama, etc). Stereo movies are true 3-D projection related to stereo slide projection in the same way that ordinary cine films are related to ordinary slide projection.

The principle involved is quite simple: two lenses are used to take the photographs which are on film moving synchronously through two gates or through two cameras. The lenses must be closely matched and are separated by the normal inter-ocular distance.

For projection two synchronized projectors, also with matched lenses, are fitted with polarizing filters and the audience wears polarizing spectacles. Wearing these spectacles causes no discomfort provided there is no variation in height between the two projected images.

This method is relatively expensive: not only does it require double the amount of film but also two cameras, two projectors, and some interlocking system to synchronize the shutters both when photographing and projecting. No other method is used commercially but for amateur work there are several adaptors available to clip over the camera lens and give two side-by-side images on the same film. A similar device used during projection reverses the process.

Mattey stereofocal. This, like the usual Kern-Paillard system, gives two side-by-side images on a normal 16 mm. film, each of the parts of the stereo pair occupying half the frame width giving vertical framing. By widening the gate aperture and utilizing the film between the perforations a horizontal frame size 6·5 × 6 mm. extending into the perforation line can be obtained. The image edges are liable to be scratched.

Stereo-Cinor gives two images of the same dimensions as the previous system but tilted 90° so that the framing and width can be maintained. In projection a similar optical device again erects the images. The more recent Murray 3-D block has the same principle.

Stereo projection methods for which spectacles are not required have recently been disclosed based upon lenticular réseau systems.

They are:

The Savoy cyclostereoscope which has a rotating mesh shaped like a truncated cone on to which the stereo pair is projected. The size of the screen is limited to the size of the rotating mesh and this is the limiting feature of this system (see Fig. 8).

The Filco relief system. This uses a flat selective grille inclined relatively to the screen. This grille is made up of fine parallel strips mounted vertically and acting as mirrors which reflect part of the projected beam on to a second screen placed in

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

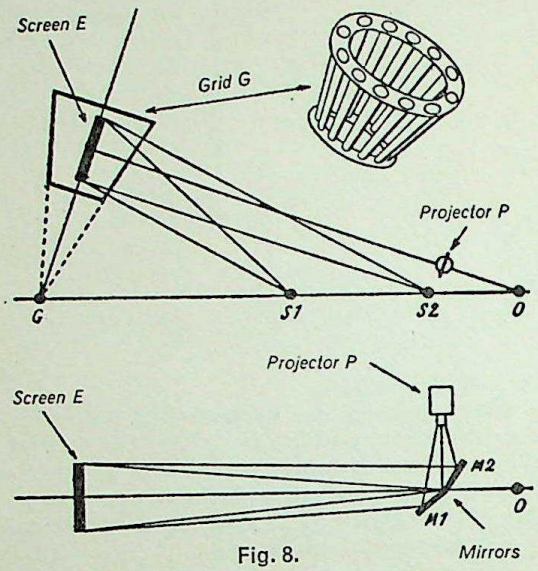


Fig. 8.

The Savoy cyclostereoscope in plan and elevation.

a corresponding position to the first screen.

The Scoplex screen (Filippi and Collas). The main requirements for a cataphot are:

(*a*) A front element L receiving incident light and reflecting it

(*b*) A rear element M receiving light refracted by L and reflecting it back towards L with a greater or less degree of diffusion or divergence depending on the system.

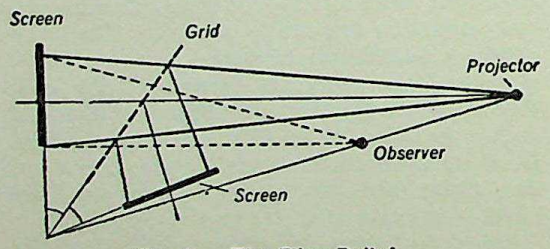


Fig. 9. — The Filco Relief.

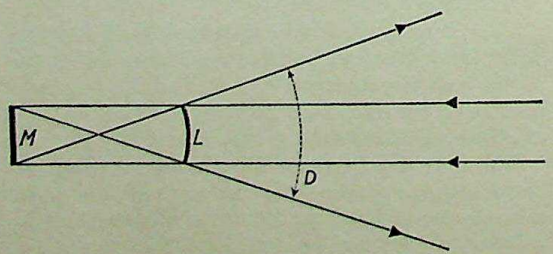


Fig. 10. — Elements of Scoplex Screen.

The screen has a regular succession of front elements L1, L2, L3 and a similar succession of rear elements M1, M2, M3, etc. Each of these elements has optical characteristics so that the divergence D of the reflected light is very low, and in any case so that the cone angle D at the normal observation distance will be received by only one of the observer's eyes.

The discontinuous nature of the screen permits the rear elements M1 to reflect back light through the apertures L1, L2, L3 . . . . . L_n to 1, 2, 3 . . . . . n spectators.

As the two stereoscopic pictures are projected from two projectors whose lenses are separated by the normal inter-ocular distance, the luminous beams coming back from the screen will be located in pairs of beams corresponding to a visual pair. It is therefore necessary for each member of the audience to be fairly accurately positioned in the auditorium in order to receive a correct stereo pair, but the luminous efficiency of this projection method is better than that of any other system.

Extrapolation and stereoscopic imagination 3-D views can be achieved by departing from the usual rules and fake results can often add to the sense of realism. The use of identical images in a stereoscope, however, should not be attempted as this elementary trick will deceive no one.

1. Inverted stereoscopy Sometimes improperly called pseudo-stereoscopy, this consists of reversing the positions of the two stereo images so that the right eye image is shown to the left eye and vice versa. The result of this inversion is that objects which should stand out appear to recede. When the opposite effect is illustrated through shadows, the spread of light or the size of familiar objects, the effect may be very strange or confusing. The deliberate use of this method should therefore be reserved for subjects which contain no recognisable features, for example, rocks, plants, submarine views, and the like.

2. Hyperstereoscopy If the distance between the two camera lenses is increased, the stereoscopic effect will be increased. If the two images are photographed from positions 20 ft. apart, distant landscapes 10 miles away will show considerable relief. There is in addition an apparent reduction in the size of the subject in proportion to the increase in the inter-ocular distance. Thus, if the inter-ocular distance is increased to n × 63 mm., the subject size will appear to diminish to 1/n normal. This is the reason why a village photographed under these conditions always looks like a model. Despite the reduction in apparent size, the system has many uses, particularly in photogrammetry and aerial reconnaissance work.

The pictures are not made simultaneously but

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

are taken in succession either using a normal camera or by taking one frame at a time with a stereo camera. The camera can either be moved along a wooden or metal base to maintain its horizontal plane or can be aligned on a distant object. The spirit level common with so many older cameras is a useful asset here. With most miniature cameras an additional frame-type viewfinder is advisable to assist in maintaining the camera horizontal.

3. Hypostereoscopy The effect produced here is the reverse of that just described; the stereo effect is reduced and the apparent size increased when the lens spacing is reduced below 63 mm. This technique can only be used in close-up work.

4. Stereo photography of small objects situated at short distances No satisfactory result can be obtained in close-up work by the simultaneous use of both lenses of a stereoscopic camera. In fact, due to the 63 mm. lens spacing, the subject may not appear on one of the images. It is therefore necessary to reduce the lens separation by exposing the two images separately and adjusting the camera position between exposures to bring the distance *d* down to a suitable value *x*. It is also desirable to move the camera slightly between exposures so that the lens axes converge by about 1° (Fig. 11).

d	*x*
10 cm.	28·9 mm.
20 cm.	26·8 mm.
30 cm.	24·7 mm.
40 cm.	22·5 mm.
50 cm.	20·2 mm.

The Jules Richard stereoscopic baseboard enables this method to be used almost automatically.

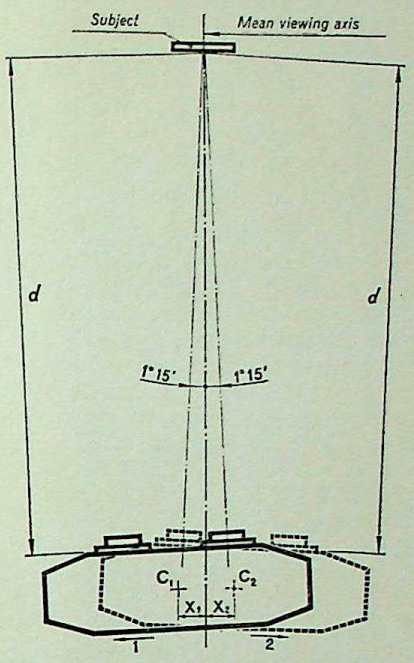


Fig. 11. — Illustration of the positions required in taking separate photographs.

When framing the subject, the vertical parallax should be taken into consideration.

If the lens extension is too short, extension tubes or close-up supplementary lenses may be necessary.

Using this technique the stereo image will appear larger; subjects about 5 ft. away will be seen completely and without any accommodation difficulties.

SUPERCINECOLOR

Introduction In this motion picture process a combination of chemical toning, such as that used in Defender's chromatone, is used with a dyestuff mordanting system. Like Chimicolor and Thomson colour, this system attempts to overcome some of the registration problems of printing from three separation negatives by using raw stock coated on both sides of the base (Duplitized stock). Two separation colour images are first produced, one on either side of the base, and the third is subsequently added without interfering with the two already present. The dye toning process and the various properties of duplitized film will be discussed before the chemical toning processes.

Dye toning from a corresponding silver image A plain gelatin layer, soaked in a solution of a basic dyestuff, can readily be washed free from dye in slightly acidulated water. If, however, the gelatine has first been treated in a solution of potassium alum, the dyestuff cannot be eliminated. Potassium alum behaves as a mordant towards basic dyes.

The alum first reacts with and is retained by the gelatin and subsequently reacts with the dye to form a lake or insoluble pigment. If the silver image is converted into a suitable mordant the latter will react with and retain basic dyestuffs of suitable colour.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

A large number of compounds which can be derived from or precipitated by the silver image have been disclosed by various workers. Almost all ferri- and ferrocyanides of heavy metals are good mordants for basic dyestuffs. In 1928 Crabtree and Ives disclosed a combined bleach and dye bath containing a ferrocyanide together with one of the following dyes:

Safranine 6B	Thioflavine T
Basic safranine	Auramine
Chrysiodine 3R	Rhodamine B

In 1907 Traube found that silver iodide was an excellent mordant for basic dyes and it eventually became the most widely used mordant. Miller carried out a great deal of work on the production of an effective and transparent silver iodide mordant. The following dyes are suitable for use with silver iodide mordants:

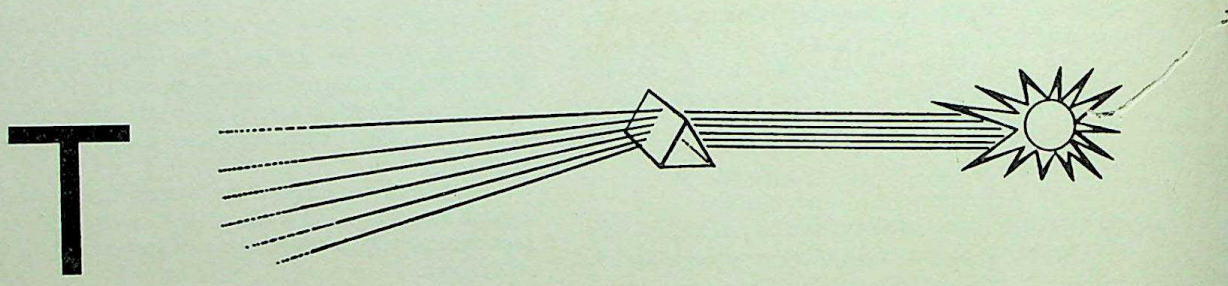
Acridine B	Methylene blue
Xylene red	Auramine
Malachite green	Methyl violet
Thionine blue	Methylene yellow

Duplitized film This consists essentially of a single base film with an emulsion layer on each side. There is also a yellow filter layer between the emulsion and the base (or alternatively the emulsions are yellow dyed) to prevent the exposure from one side affecting the emulsion on the reverse side.

Supercinecolor processing Firstly the red and green separations are printed from either side of the duplitized stock. After development there are two silver images which have to be converted to cyan and magenta respectively. To treat each face independently of the other the film is floated across the surface of the processing solution.

In the first stage one image is converted to prussian blue (cyan image) — see Chromatone process. At a later stage the silver ferrocyanide is converted back to silver bromide. After washing the film has on one side a cyan image and reformed silver bromide and on the other side a silver image in residual silver halide. The blue separation is then printed on to the side which already carries the cyan image. This image is developed by flotation, taking care not to develop the other side of the film which is not fixed and has not been protected by a yellow dye.

Both sides of the film are then fixed by immersion. The silver images are converted to silver iodide and each image is dyed yellow or magenta by flotation on a basic dyestuff solution.



TECHNICOLOR

Technicolor was the first really successful motion picture colour process, since it was the first one, sufficiently controllable, to be used commercially on a large scale. The diagram shows how the three necessary separation negatives could be made simultaneously in a beam-splitter camera.

The light from the lens passes through a prism block which has a partially reflecting mirror surface at 45° to the lens axis. The direct beam transmitted through this reflector emerges from the prism and passes through a yellow filter to an orthochromatic film which therefore records the green aspect.

After emerging from the prism block the reflected beam strikes the base of an ordinary (blue-sensitive) emulsion. The front surface of this film is coated with an orange/red dye layer to absorb the blue and green light transmitted by the first film. In contact with this film, emulsion-to-emulsion, is a highly red-sensitive film for recording the red aspect.

The three colour records are therefore obtained as follows:

1. The green record on an orthochromatic film behind a yellow filter.
2. The blue record on an ordinary film, and
3. The red record behind the red filter of the front element of the bipack.

The positive printing operation takes place in two stages.

1. The production of silver positives from the separation negatives and the conversion of

STEEL FURNACE — photograph by Alfons Rudolf using a Retina Reflex camera with Kodacolor film plus fill-in flash. ▶

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

these to gelatin matrices.
2. The printing of the three-colour image by the imbibition system using these matrices.

Full details of this process have not yet been released.

TELCOLOR (Negative-positive process)

Telcolor is a negative-positive system in which a conventional type of colour negative is used. Through the colour development step a yellow image is obtained in the outer layer, a magenta image in the middle layer and a cyan image in the bottom layer. Only one type of negative is manufactured suitable for use either in daylight or artificial light. Colour differences are eliminated with filters during printing in the usual way. It is recommended that only the Telco filters No. 80 for direct light or 85 for indirect lighting should be used when processing the film.

PROCESSING OF TELCOLOR NEGATIVE
using Telco kit

	STAGE	NOTES	TEMP.	TIME in min.
1	Colour development	—	65°F	8
2	Washing	In running water	65°F	15
3	Bleach	—	65°F	5
4	Washing	In normal room light	65°F	10
5	Fixing	—	65°F	5
6	Washing	In running water	65°F	20
7	Drying	—	95°F max.	—

TELCOLOR (Positive film)

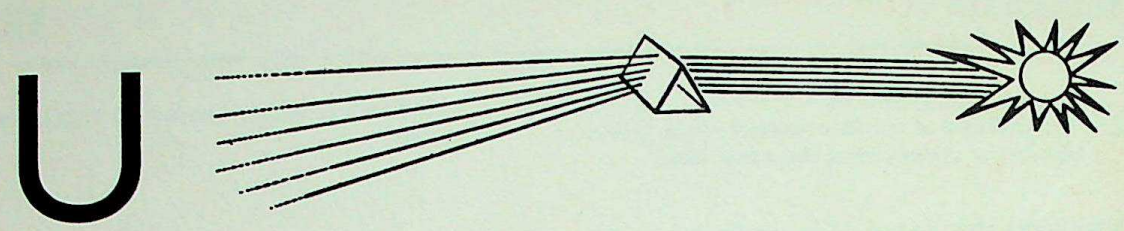
Telcolor positive film is designed for use in conjunction with a Telcolor or similar complementary colour negative for the production by contact or enlargement of transparent positives for projection or viewing by transmitted light. Its speed is approximately half that of the Telcolor paper; the printing operation is very similar to positive paper printing. Filters are used in the same way to correct colour discrepancies due to the printing light or the negative (see Negative-Positive Printing).

PROCESSING OF TELCOLOR POSITIVE

	STAGE	NOTES	TEMP.	TIME in min.
1	Colour development	Internegative developer	65°F	10 to 12
2	Washing	In running water	45–60°F	10
3	Bleach-fix	In normal room light	65°F	20
4	Washing	—	45–60°F	5
5	Hardening	CPH bath with or without formalin	65–68°F	10–15
6	Final wash	In running water	45–60°F	10
7	Drying	—	95°F max.	—

M

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



ULTRA-VIOLET AND COLOUR PHOTOGRAPHY

Principle Invisible ultra-violet radiation affects colour films in a manner which cannot readily be assessed and it should therefore be eliminated from the light which reaches the film.

Practice The spectral sensitivity is not the same for colour film as it is for the eye; in particular the colour emulsion is sensitive to invisible ultra-violet radiation which gives the picture a strong bluish cast. To some extent the colour films spectrum extends into the near infra-red where an orange-red cast will be produced but to a lesser degree. With full sunlight or electronic flash illumination the balance between the two effects will be such that they are not noticed; they may however result in some desaturation of colours. This effect is noticeable in photographs taken in hot countries, in mountains or sometimes on sunlit beaches.

The effect can be considerably reduced with a good ultra-violet filter. Such filters will eliminate the bluish cast, particularly in long-range shots, and will improve saturation. The infra-red effect will, however, still remain and in some cases will result in a rather warm picture. What is really required is a filter which absorbs both ultra-violet and infra-red but such filters are not available. All that can be done is to use an ultra-violet absorber together with a heat-absorbing filter. Another approach to the problem is to use a material balanced for tungsten lighting and an orange correction filter such as a Wratten 85 or 85B, depending on the film type, over the lens. This will balance the tungsten emulsion to daylight without too great a loss in speed and will also eliminate the ultra-violet.

UNDERWATER PHOTOGRAPHY

Underwater photography is complicated by the fact that water has optical properties which differ considerably from those of air. Furthermore these properties vary considerably with location and even at the same depth may vary from day to day. The figures given later are only valid for very clear water like that of the Mediterranean. Photographers wishing to work off the British coast or in rivers or lakes will have to modify the figures according to experience. The magnitude of the optical variation remains the same regardless of the turbidity of the water.

Selective light absorption by water Water absorbs light in the near infra-red and in the far ultra-violet. Between these two regions it is transparent, with the maximum transmission about 490 mμ in the blue-green region. Fig. 1 shows the variation in the transmission factor of water measured in the Mediterranean off the coast near Nice in normal clear conditions for the region and for the season. Care was taken to avoid the muddy water near the mouth of the River Var. This curve is unsymmetrical about its peak as absorption increases more rapidly at long wavelengths than at short ones.

The absorption of sunlight by sea water results in a considerable loss of light as the depth increases. A rough exposure guide is given opposite for a black-and-white emulsion of 50 ASA (28° BS), and for a colour emulsion of 10 ASA (21° BS). The

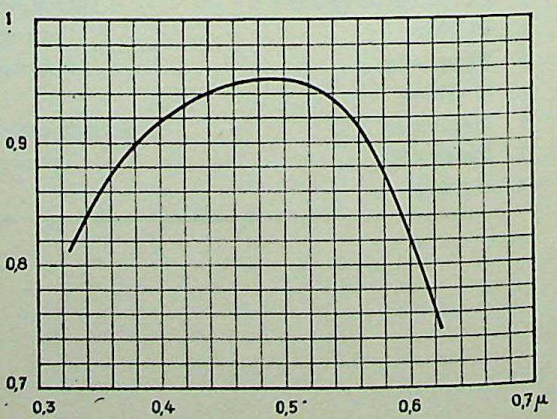


Fig. 1.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

	50 ASA	10 ASA
On the surface	$\frac{1}{125}$ f/12·5	$\frac{1}{60}$ f/6·3
3– 6 ft. below surface	$\frac{1}{125}$ f/8	$\frac{1}{60}$ f/4
15– 30 ft. below surface	$\frac{1}{60}$ f/8	$\frac{1}{30}$ f/4
30–100 ft. below surface	$\frac{1}{60}$ f/4	$\frac{1}{30}$ f/2·8
100–150 ft. below surface	$\frac{1}{60}$ f/2·8	$\frac{1}{30}$ f/2

use of higher sensitivity emulsions is accompanied by an increase in grain which is particularly noticeable on the relatively even areas found in underwater scenes.

This table is of use only when the surface lighting conditions are full sunlight in the middle of the day in summer, and applies only to very clear water. For black-and-white work where the exposure latitude is considerable the guide may be used directly but the more critical exposure requirements of colour stocks call for an exposure meter mounted in a suitable watertight box. The difference in reading, depends on whether the meter is held horizontally, pointed towards the surface, or directed towards the bottom, is considerable.

The selective absorption of sunlight by water shows a rapid disappearance first of red, then of orange and yellow, as the depth increases. Below 30 ft. photographs will generally show an even blue-green coloration corresponding to the visual impression at that depth. For depths less than 30 ft. daylight emulsion should be used because of its greater sensitivity to red and yellow but at greater depths the extra speed in the blue and green of tungsten balance stocks is an advantage.

Theoretically it is possible to reduce or even eliminate the blue cast when working at 15 or even 30 ft. by using an orange filter whose strength increases with the depth of water, but this method does not appear to be either very practical or very useful. The filter will on the other hand be useful for black-and-white work up to 30 ft. as it will darken the background — the sea — and tend to lighten any objects immersed in the sea and thereby increase the contrast. Below 30 ft. where there is no appreciable light beyond the mid-green the use of a yellow filter would only cut down the general illumination.

Light diffusion by sea water Unlike distilled water which by Rayleigh's law has only a slight diffusing effect on light, sea water causes considerable light diffusion. This is due to the suspended particles of solids and gases consisting of mud, decomposition products of seaweed, plankton, etc, which diffuse light strongly and unselectively, as far as wavelength is concerned. The underwater photographer is, therefore, working in surroundings similar to a fog which is bright at the top and dark at the bottom and which cannot be eliminated by filtration as can ordinary mist. The more disturbed the water the greater the turbidity; this will reduce the depth of shadows and therefore the contrast. As this effect increases with distance all distant objects will disappear in haze. In the worst conditions subjects will have no usable contrast at distances beyond 10 to 15 ft. For the best results 6 to 10 ft. should not be exceeded and around the British coast 3 ft. may well be the limit. It is therefore an advantage to take photographs from the closest possible range and a wide-angle lens is a most valuable asset in underwater photography.

Refraction of water The refractive index of water relative to air is 4:3 (see Light). This difference in refractive index has important effects when the light has to travel through water and then through the air-filled water-tight camera container. At the interface between water and air, i.e. the glass panel in front of the camera lens, the light will be refracted according to Descartes' laws (Fig. 2). It is in fact not the object AB which is photographed but its image A′B′; the object has in effect been magnified and brought nearer due to the air/glass interface in the ratio of 4:3 or 3:4 respectively. The field of view has therefore been reduced in proportion to the magnification and the depth of field is also reduced. This is a considerable disadvantage for, as we have seen, diffusion effects encourage the photographer to use lenses with as wide a field of view as possible and the use of extreme wide-angle lenses is frequently accompanied by distortion at the edge of the field.

To overcome this effect the plain glass port can be replaced by an underwater supplementary lens which produces an image A′B′ in virtually the same plane and of the same size as the object AB (Fig. 3). This lens consists of two elements, the first of which is in direct contact with the water. Using this supplementary lens the normal characteristics of the camera lens are unchanged. Unsharpness and lack of linearity, even with wide-angle lenses, are no longer seen. Furthermore there is no loss of depth of field. Focusing is carried out normally at the object's actual distance instead of

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

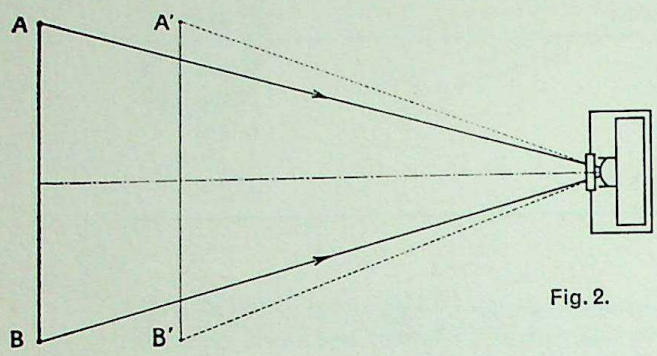


Fig. 2.

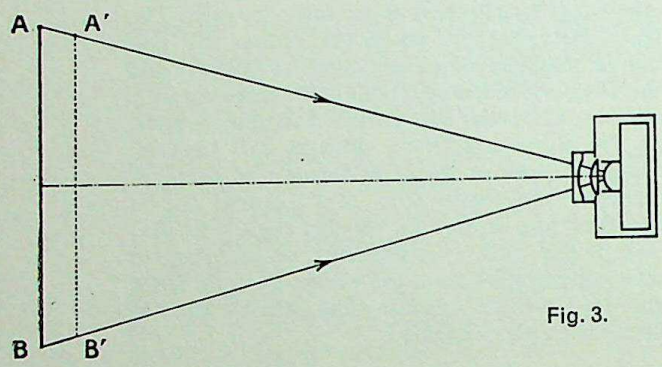


Fig. 3.

at three-quarters of this distance necessary when a plain glass port is used.

The increasing popularity of underwater photography will probably lead to the commercial introduction of special lenses incorporating this supplementary front cell for underwater work. These lenses will of course be quite useless for photography in air.

The use of artificial light sources As we have just seen, underwater colour photography using daylight is only successful to a limited extent. Undoubtedly the underwater world is full of a wide range of beautiful colours which cannot be seen owing to the enormous blue filter through which the sunlight must be transmitted. The obvious way of overcoming this is to use artificial light sources underwater—flashbulbs or electronic flash for still photographs or flood lamps for motion picture work. It should not be forgotten that artificial light sources are also useful in black-and-white work to increase contrast, to shoot against the light or to work in shadow or caves.

At present a wide variety of light sources for underwater work is available but in all cases the optical properties of working in sea water must be considered. Due to the high absorption of the water, the fall-off in illumination is greater than one would expect from the inverse square law (see Photometry). When the distance from light source to subject and back to the camera exceeds 10 to 15 ft. the blue-green coloration due to the sea water will become appreciable. The photographer should always work as close as possible to the subject and use wide-angle lenses to overcome this difficulty. The light sources may be located closer to the subject than the camera position but if this is done the illumination field must be wider than the camera field or the edges of the image will not be fully exposed.

The bluish cast at distances over 15 ft. could be overcome by using an orange filter but at these greater distances the turbidity of the water and its adverse effect on contrast become significant. It is therefore rather pointless to try to build up lighting units of extreme brilliance as the limiting factor on distance is this diffusion. To reduce diffusion effects the less water between the camera and the subject the better. This can be achieved by placing the light source in front and to one side of the camera; the use of two light sources symmetrically placed on either side of the camera will greatly assist the production of an even field. This method involves considerable extra expense and a lot of extra equipment without greatly increasing the distance at which photographs can be taken. A general recommendation is to work no further than 6 ft. from the subject, and at the same time keep the light sources at 2 to 3 ft. from the subject and outside the camera field.

When expendable flashbulbs are used daylight film gives excellent results at distances of about 3 ft. as the water behaves like a correction filter. With electronic flash daylight film is naturally used but with the addition of a yellow filter to cut down excess blue, particularly if the subject is more than 6 ft. away. For motion picture work artificial light film should be used with the floodlamps together with an additional yellow filter if the subject is more than 6 ft. away; to obtain adequate illumination a power of several kilowatts must be available which generally puts such products outside the amateur field.

USE OF COLOUR SLIDES

Examination of photographs Processed film will be received from the laboratory either card-mounted or in strips according to the wish of the user. Card-mounts are satisfactory for occasional use or in magazines but give little protection to the film. Where considerable handling of the film is anticipated mounting between glass is preferable and for this purpose it is best to receive the film from the laboratory in strip form. When making experimental exposures such as the relationship

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

between meter reading, film speed and camera setting, the strip form enables the different exposures to be compared and assessed more easily. When film is requested unmounted, particular care should be taken not to handle the film unnecessarily when it is first received. It may still be in a rather tender state and susceptible to damage so the good transparencies should be removed from the strip and mounted between glass as quickly as possible. If immediate mounting is not practicable a transparent or translucent sleeve should be used to protect the film.

Mounting transparencies The main problem with 24 × 36 mm. transparencies is in the selection of the most suitable mounts. Whilst many careful amateurs project successfully using standard card-mounts the use of protective glasses is highly recommended as it prevents the film from buckling during projection and protects it completely from any scratches, abrasions or dirt.

The transparencies to be mounted are separated by cutting along the black mask line. The following points should be noted.

1. Rubbing with a rag frequently gives the film a static charge in which condition it attracts dust.
2. A very soft brush is the best method of removing dust from the transparencies. Anti-static brushes containing a polonium strip are now available; these discharge any accumulated static electricity and release the attracted dust.
3. Only the edges of the film which are not viewed should be handled; it is best to wear thin cotton gloves when handling miniature colour film but anyone finding gloves too great a hindrance may prefer to use philatelists' tweezers.
4. When mounting, care should be taken that the cover glasses are perfectly clean; when using card-mounts any whiskers of paper should be rubbed from the aperture with the finger tip.

If any masking is to be done beyond the usual 24 × 36 mm. aperture, black adhesive tape should be used over the mask — never on the outside of the glass where it would not focus properly and would result in a very unsatisfactory frame line. Slight colour corrections can be introduced at this stage by mounting a gelatin filter of suitable density and hue with the transparency. This should never be allowed to develop into a routine method as it does not give highest quality results.

Data concerning each slide may be recorded either on the slide itself in an abbreviated form or more fully in a notebook kept with the slides by using a reference number system. The slides should finally be spotted at the bottom right corner when looking at the transparency so that a correct picture is seen. This will ensure the slide being put into the projector the correct way round.

Making a slide collection Unless some orderly system is adopted for organizing a collection of slides it will always be difficult to avoid misplacing or losing some of the mounted transparencies. One convenient method of slide storing is the grooved wooden box from which a slide may be taken and replaced at will. If a similar type of box is used but without the individual grooves for each slide, there will be a considerable saving in space but it is less easy to select a single slide.

Slides should be divided into two groups in any type of collection. Firstly there are the personal subjects of interest to one's family and close friends which illustrate personal events without any particular artistic or technical pretensions. Secondly, there is the group for more general exhibition which should be technically perfect and carefully mounted, free from scratches or dust. The choice of subjects is unlimited:

Landscapes, towns, rivers, memorials, etc.

Natural science: animals, plants, flowers, minerals, gems, crystals, etc.

Human interest: portraiture, regional or national dresses, sports, camping, yachting, nudes, children, theatre and music hall, circus, street markets, handicrafts, etc.

News: ceremonies, exhibitions, festivals.

Architecture: visual arts, paintings.

Effects of colour and light: rainbows, soap bubbles, fireworks.

A series of ten to thirty slides will provide valuable illustration for most subjects — fifty or more may be needed to depict a country. Such groups of similar subjects will have far greater impact than single odd slides shown at random.

Commercial value of colour transparencies A number of markets exist for good colour photographs. Industry is always needing photographs of its achievements and there is a large market in the magazine world. The choice available to the purchaser is, however, extremely wide and the requirements are such that only the best slides from a collection will be selected, the amateur may not wish to part with these or may expect too high a price.

To avoid having to part with one's best slides, subjects which appear to be saleable can be photographed twice or copy transparencies may be made.

Photographs submitted for reproduction must be perfectly sharp, and have good colour rendering. Density should be normal or a little on the dark side with dense neutral blacks; over-exposure must be avoided. For magazine work vertical framing is more acceptable. Most cameras and particularly the 35 mm. ones so popular with the colour worker are more convenient to use with horizontal framing and it is therefore very important to consider the purpose for which a photograph is required before pressing the shutter.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

UTOCOLOR PROCESS

General The basic principle of this process is the tendency of an unstable dye to be bleached to the colour of the light to which it is exposed. The method was investigated by Liesegang in 1889.

According to the Grotthus-Draper law a photochemical effect only results when the photosensitive substance effectively absorbs the irradiating light. A yellow dyestuff will, therefore, be affected by blue or ultra-violet light (complementary colour). A magenta dyestuff will absorb and be changed by green light and a mixture of yellow, magenta and cyan dyes will absorb the whole spectrum. This is an ideal situation enabling colour positives to be produced directly from separation negative (see sketch, page 37).

Despite this theoretical possibility, processes depending on this phenomenon have had scant commercial attention. The Utocolor process introduced by J. H. Smith in 1910 suffered from two overwhelming disadvantages.

1. The extreme slowness of the photolytic bleaching.
2. The stabilization of the image.

The feature of Utocolor was the introduction into the sensitive mixture of an accelerating agent which would speed up bleaching but which could be eliminated when the process had gone far enough. The accelerator which Smith used was thiosinamine but the material was still very insensitive and did not yield a good white.

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

LIST OF COLOUR FILMS
FOR STILL PHOTOGRAPHY AND CINE PHOTOGRAPHY

D = Daylight A = Artificial (Tungsten) ■ = sheet films ○ = roll films

● = 35 mm. ○ = 16 or 8 mm.

Reversal Colour Films

FILM	TYPE*	ASA INDEX D	ASA INDEX A	FORMATS	REMARKS	PROCESSING RIGHTS INCLUDED IN COST
Adox CT 18	D	50		●		Yes
Agfacolor CT 18	D	50		○ ● ○		Yes
CK	B		32	○ ● ○		
CK 20	T		80	●		
Anscochrome	D	32		■ ○ ● ○		No Special Kit or Colour Laboratory
Anscochrome Super	D	100		■ ○ ●		
	B		100	○ ●		
Ektachrome E-2	D	32		○ ●	*With Wratten 85C †Photoflood with 82A	No E-2 Processing Kit
	F	20*	16†	○ ●		
High Speed	D	160		○ ●		
	B		125	●		
Ektachrome E-3 (Professional)	D	64		■ ○		No E-3 Processing Kit
Ferraniacolor	D	20		■ ○ ● ○		No Processing Kit
	B		20	■ ○ ● ○		
Gevacolor R5	D	40		■ ○ ● ○		Yes
Ilfachrome 32	D	32		●		Yes
Kodachrome	D	10		● ○	*With Wratten 85C †Photoflood with 82A ‡With Wratten 85	Yes (except in U.S.A.)
	F	10*	10†	●		
	A	16‡	16	● ○		
Kodachrome II	D	25		● ○		
Perutzcolor CT 18	D	50		●		Yes

Negative Colour Films

Adox NC 17	D	40		■ ○ ●		No
Agfacolor CN 17	D	40		■ ○ ●		No
CN 14		20		●		
Ferraniacolor	D	16		■ ○ ● ○		No
Gevacolor N5	D	25		■ ○ ● ○		No
Ilfacolor	D	32		○ ●	May be exposed with clear flash bulbs	No
Kodacolor	D	32		○ ●	May be exposed with clear flash bulbs	No

*Type A=3,400° K, Type B=3,200° K, Type F=3,800° K (clear flashbulb), Type T=2,900° K

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

INDEX

A

Additive (Processes) 7
Adox (Reversal colour film) 9
Adox Color CN17 (Negative colour film) 9
Agfacolor Processes 140
Agfacolor (Negative-positive process) 9
Agfacolor (Reversal process) 9
Air Photography 9
Anscochrome and Super Anscochrome (Reversal process) 11
Anscochrome Printon Processing 144
Artificial Light 12
Autochrome Plates 7

B

Black-and-White Prints 15

C

Cameras 16
Carbon Process 19
Carbro Process 20
Carbro (Practical details) 21
Child Photography 23
Chimicolor Process 24
Chromatone 25
Colorimetry 25
Colour 29
Colour Cinematography 32
Colour Cinematography (Commercial processes) 41
Colour Developers 42
Colour Development 125
Colour Image Quality 43
Colour Rendering 43
Colour Temperature Meters 49
Colour Vision 49
Coloured Couplers 52
Couplers 54

D

Daylight 56
Defects of Colour Films 59
Densitometry 153
Discharge Lamps 14
Documents and Works of Art 61
Dufaycolor 8
Duxochrome Process 62
Dye Transfer Process (Kodak) 63

E

Eastmancolor 64
Ektachrome (Reversal colour film) 65
Ektacolor (Negative colour film) 67
Electronic Flash 14
Exposure 67
Exteriors 71

F

Ferraniacolor Processes 140
Ferraniacolor (Negative-positive process) 73
Ferraniacolor (Positive film) 74
Ferraniacolor (Reversal process) 74
Filters 74
Flashbulbs 13
Flexichrome Process 80
Flower Photography 81
Fluorescence 82
Fluorescent Lamps 14

G

Gasparcolor Process 84
Gevacolor (Reversal film) 85
Gevacolor (Negative-positive film) 85

H

Half-tone 128
History of Colour 85

I

Ilfachrome (Reversal colour film) 88
Ilfachrome (Negative colour film) 88
Incandescent Lamps 12
Influence of Sun's Elevation 56
Influence of Atmospheric Conditions 58
Interiors in Colour 88

J

Johnson Process 8

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

K

Kodachrome (Reversal process) 90
Kodacolor (Negative-positive process) 92

L

Laboratories 93
Lenses 94
Light 96

M

Make-up 107
Marine Photography 108
Masks 109
Medical and Scientific Colour Photography 112
Miscellaneous (Colour) 113
Mountain Photography 114

N

Negative Material 92
Negative-Positive Printing 115
Negative-Positive Processes 120
Night Photography 121

P

Pérutzcolor Film (Reversal colour film) 122
Photographic Process (Basic) 122
Photographic Reproduction of Colour 123
Photographic Technique 131
Photogravure 130
Photomechanical Printing 128
Photometry 132
Pinatype 136
Polarization 137
Portraiture in Colour 138
Positive-Positive Printing 140
Print paper 92
Printing equipment 119
Printing Processes: negative-positive 140
Printing Processes: positive-positive 144
Projection 146

R

Reciprocity (Law failure) 147
Reflection Prints 148
Reversal Processes 150

S

Sensitometry 151
Sensitometry of Colour Materials 152
Separation Negatives 155
Shutter Calibration 156
Spectral Sensitivity 157
Spelaeology (Cave) 158
Stained Glass Window Photography 159
Stereo Photography 160
Supercinecolor 167

T

Technicolor 168
Telcolor Processes 140
Telcolor (Negative-positive process) 169
Telcolor (Positive film) 169

U

Ultra-violet and Colour Photography 170
Underwater Photography 170
Use of Colour Slides 172
Utocolor Process 174

W

Wood's 'Black' Lamps 14

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

KODAK

FIRST CHOICE FOR COLOUR

KODACHROME FILM

The world's most famous colour film. 35mm and 828 sizes for colour slides. 8mm and 16mm for movies.

EKTACHROME FILM

Gives brilliant colour transparencies with a wide range of cameras. 35mm, 120, 127, 620 and sheet sizes; 16mm for movies.

HIGH SPEED EKTACHROME FILM

A really fast film for colour transparencies of action and available light shots. 35mm and 120 sizes.

KODACOLOR FILM

The colour negative film for superb colour prints. 35mm, 120, 127, 620, 828 sizes.

EKTACOLOR FILM

Colour negative film in sheet sizes.

EASTMAN COLOUR FILM

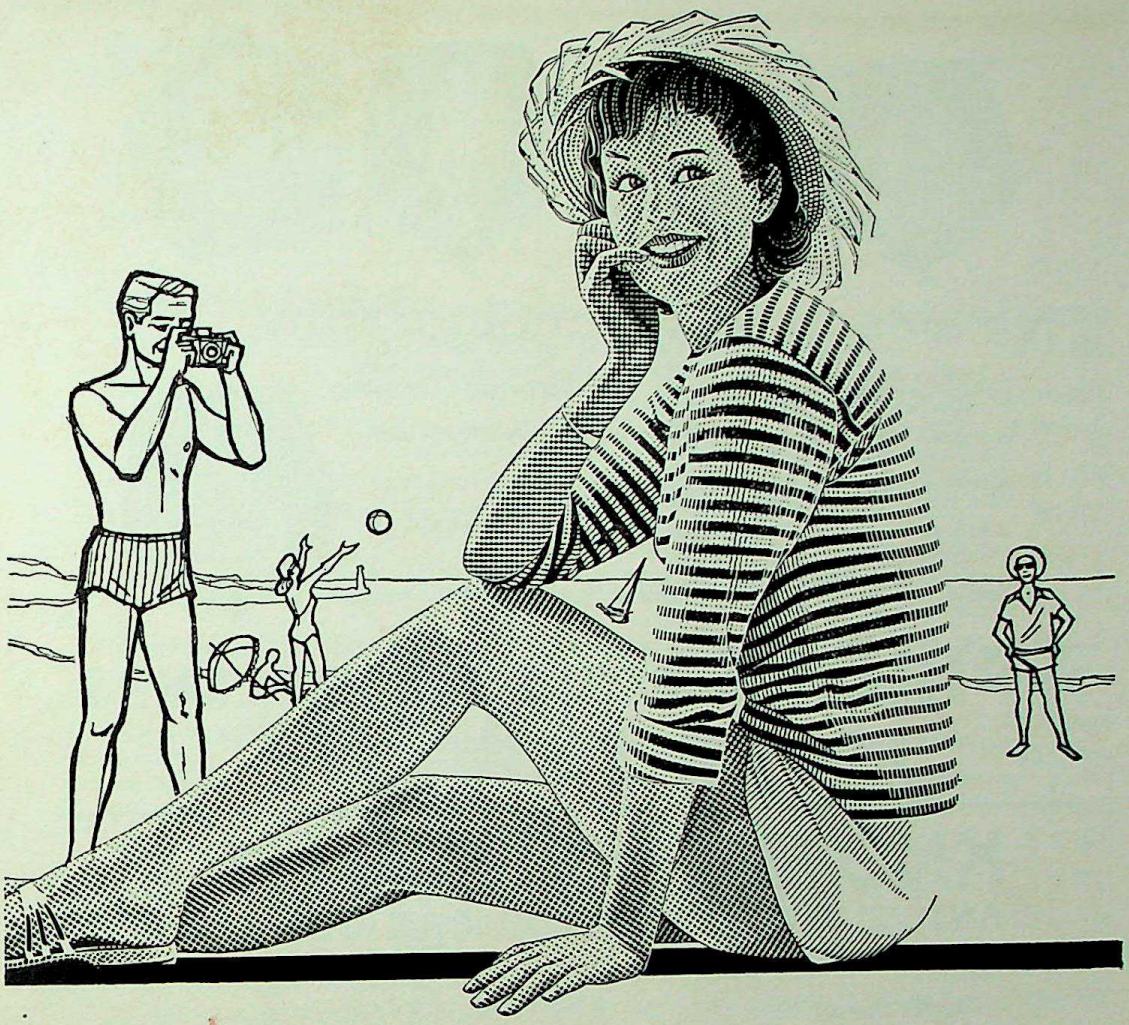
The 35mm colour film for the professional motion picture maker.

for every user, for every use of colour photography —

KODAK

FIRST CHOICE FOR COLOUR

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



GEVACOLOR

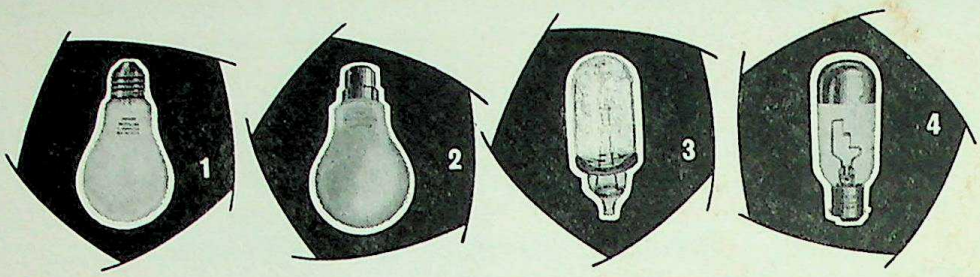
for better colour prints and transparencies

High days . . . holidays . . . let's-have-a-picnic days, all through the year you can take beautiful, natural colour on GEVACOLOR N5 Negative and GEVACOLOR R5 Reversal film.
For movies use GEVACOLOR R5 Reversal Cine Film.

GEVAERT

FROM YOUR USUAL DEALER

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh



Five aids to better photography

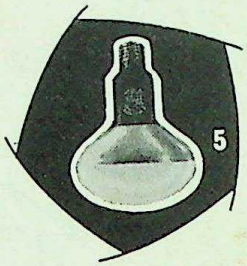
1 Philips 'Photocrescenta' Enlarger Lamps 75w and 150w both available in 60 mm. bulb, with either ES or BC cap in all voltages. Specially designed for use with the Photographic Enlarger.

2 Philips 'Photolita' Lamps High-efficiency Photoflood lamps available in high voltages with ES and BC cap. ES cap only in low voltage.

3 Philips 'Photoflux' Flashbulbs Three types available : PF 1 ; PF 1B ; PF 5. For all flash photography in monochrome and colour.

4 Philips Projector Lamps Wide range of high-efficiency lamps available. Suitable for all still or cine projectors.

5 Philips Reflector Photoflood Lamps Both the SM (275w) and NM (500w) are supplied with built-in reflectors. Light-weight, portable. NM is suitable for indoor cine.



PHILIPS **PHILIPS PHOTOGRAPHIC LAMPS**

superbly efficient—completely dependable

PHILIPS ELECTRICAL LIMITED, LAMP & LIGHTING GROUP, CENTURY HOUSE, SHAFTESBURY AVENUE, LONDON, W.C.2.

KNOW YOUR CAMERA

AND THE RESULTS YOU CAN GET FROM IT

READ:

Contaflex Manual by Edward S. Bomback	**35s. 0d.**
Exakta Manual by Werner Wurst	**45s. 0d.**
The Leica and the Leica System by Theo M. Scheerer	**37s. 6d.**
Leica Manual and Data Book by Willard D. Morgan and Henry M. Lester	**63s. 0d.**
Leica in Professional Practice by Heinrich Stöckler	**50s. 0d.**
Linhof Practice Edited by Nikolaus Karpf	**63s. 0d.**
Retina Manual by Edward S. Bomback	**45s. 0d.**
Rollei Manual by Alec Pearlman, FIBP, FRPS, FRSA	**45s. 0d.**
Exakta Handbook by K. L. Allinson, ARPS	**15s. 0d.**
Retina Handbook by Edward S. Bomback	**15s. 0d.**
Rollei Handbook by A. Pearlman, FIBP, FRPS, FRSA	**15s. 0d.**

FOUNTAIN PRESS LTD. 46–47 CHANCERY LANE, LONDON, WC2

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

FOR YOUR BOOKSHELF

'The purest and most thoughtful minds are those which love colour the most' JOHN RUSKIN (1819–1900)

Better Colour with Walther Benser — **Walther Benser**
A word and picture guide to successful colour photography. **27s. 6d.**

Colour Photography for Pleasure — **Edward S. Bomback**
A Fountain paper-back by this well-known author. **Terrific value at 3s. 6d.**

Filming in Colour — **Derek Townsend, MBKS, AICF**
Covers the whole range of problems facing the colour shooter. **8s. 6d.**

How to use Filters — **G. Gordon Bates, AIBP, ARPS**
How to choose and use the right filter for every occasion. **8s. 6d.**

Making and Printing Colour Negatives — **John Vickers, FIBP**
A complete course in the use of colour print material, by a master. **30s. 0d.**

My Experiences in Colour Photography — **Dr Paul Wolff**
Fifty-four pictures with technical data by great colour pioneers. **50s. 0d.**

Photographing Colour — **Walther Benser**
A mine of information. Hints and illustrations on almost every page. **37s. 6d.**

The Reproduction of Colour — **R. G. W. Hunt, PhD, DIC, ARCS, FRPS**
The theory of colour reproduction in photography, TV. and print. **63s. 0d.**

Taking Colour Photographs — **George Ashton**
How colour processes work and how to make the most of colour films. **12s. 6d.**

Pilkington on Colour Photography — **W. J. Pilkington, FIBP, FRPS**
Nos. 1–6 in the well-known Colourfacts series, bound in one volume. **48s. 6d.**

Your A–Z Guide to Colour Photography — **Edward S. Bomback**
An alphabetical guide to every aspect of colour photography. **12s. 6d.**

Amateur Colour Printing — **Conrad Frost**
Containing chapters on every aspect of colour printing **8s. 6d.**

Portraits in Colour — **Edward S. Bomback**
Complete course on coloured portraiture **8s. 6d.**

Close-ups and Copying in Colour — **Edward S. Bomback**
A practical introduction to the art of close-up photography **8s. 6d.**

Photography in Colour with Kodak Film — **Edward S. Bomback**
Get the best from your camera using Kodachrome, Ektachrome and Kodacolor. **15s. 0d.**

From your bookseller, photodealer, or in case of difficulty from

FOUNTAIN PRESS LIMITED
46-7 CHANCERY LANE, LONDON WC2

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

magazines to increase your knowledge of photography

Specializes in small format photography.
Contains photographs and articles by the leading workers in this field, competitions, equipment reviews and informed comment on the latest trends.

Monthly 2s. 0d.
Annual Subscription
30s. 0d.

Monthly 2s. 6d.
Annual Subscription
36s. 0d.

For all colour users from the casual 'snapshot-taker' to the practising professional in search of new ideas and angles.
First-class colour plates and informative articles illustrated by drawings and photographs.

Available from your newsagent or photographic dealer
Annual subscriptions from the Subscription Manager

FOUNTAIN PRESS LIMITED
46–47 CHANCERY LANE, LONDON, W.C.2

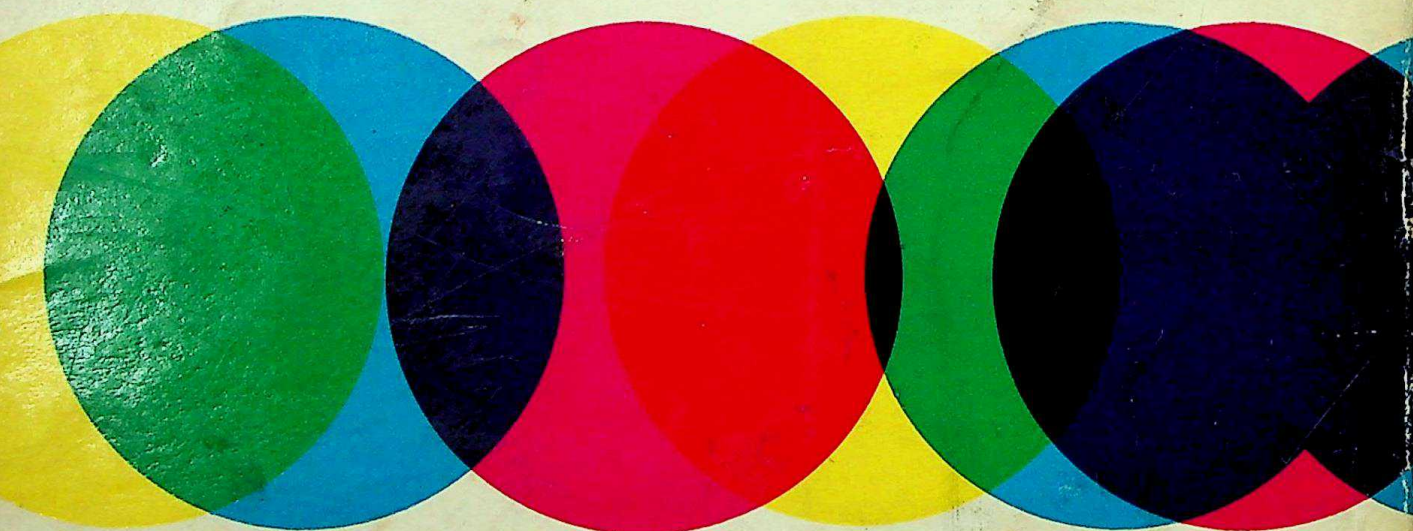
CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh

CC-0. Agamnigam Digital Presevation Foundation, Chandigarh